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Contents

A DESCRIPTION OF THE ASTRONAUT'S TASK IN PROJECT MERCURY 149
Robert B. Voas

PERCEIVED MOVEMENT IN DEPTH AS A FUNCTION OF LUMINANCE AND VELOCITY 160
Charles A. Baker and William C. Steedman

AIRCRAFT GROUND EMERGENCY EXIT DESIGN CONSIDERATIONS 174
John A. Roebuck, Jr. and B. H. Lovedahl

THE AUTHORS 210

EDITORIAL 211

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A Description of the Astronaut's Task in Project Mercury[1]

ROBERT B. VOAS, NASA Space Task Group.

The integration of the man in the Mercury system is discussed in terms of his contribution to system reliability and flexibility. Eight basic flight tasks are described. In addition, the contributions of the astronauts to the development of the Mercury vehicle are outlined. Also considered are the possible applications of Mercury human factors experience to future space flight programs.

Man's versatility and selectivity, his ability to perceive the significance of unexpected and unprogramed findings, or to react intelligently to unanticipated situations have not been simulated by any combination of physical devices, however complex, which have been developed or even contemplated. Human intelligence and manual skill in servicing the complex mechanism of space vehicles or repairing breakdowns in flight are not readily dispensed with or replaced. When along with these attributes are considered his weight of 72 kg, his total resting power requirements of 100 W, his ability to function for years without maintenance or breakdown, then even the most elaborate provisions for his sustenance, welfare and safety are amply justified simply in terms of engineering efficiency.[3]

ASTRONAUT'S ROLE IN MERCURY SYSTEM

The Mercury vehicle is designed as an automatic system which, if all components work correctly, can complete an unmanned flight. This fact has sometimes obscured the important role that the astronaut will play in the operation of the system during manned flights. The extent to which the astronaut has control over the Mercury vehicle operation is frequently misunderstood. At first view, the lack of control over the booster at launch and the lack of a horizontal landing capability has sometimes led to the erroneous conclusion that the astronaut was a passive-observer passenger aboard the Mercury vehicle. This attitude overlooks the fact that the astronaut has complete control over attitude in orbit and on re-entry and that he has control over secondary power in orbit. It overlooks the more basic consideration that attitude control, which is the central problem in piloting aircraft, may be less significant in space flight. Experience in Project Mercury tends to indicate that the pilot's role in backing up his onboard systems and taking over in the event of malfunction is a very demanding and time-consuming task. It is not the purpose of this paper to defend man's role in space-flight systems. It is, however, basic to an understanding of the astronaut's task in Mercury to recognize that the job demands levels of skill similar to those required in flying high-performance aircraft. The astronaut's task from a pilot's point of view was the subject of a paper presented by one of the Mercury astronauts, Capt. D. K. Slayton, at the Society of Experimental Test Pilots (October 9, 1959).[4]

The integration of the astronaut in the Mercury system provides added reliability and flexibility of flight. His role can be illustrated by the schematic sequence diagram for the retrograde portion of the mission given in Fig. 1. (Note that the prefix "retro" is adopted herein as a simplification for terms associated with the retrograde maneuver.) Above the dotted line are the components which must function automatically in order successfully to carry out the retrograde maneuver during unmanned flights. In some cases, provision is made for redundant systems; for example, either the clock may be reset to start retrofire or a direct command signal is available to start this sequence. In other cases, however, only

[1] Presented at the Fourth Annual Meeting of the Human Factors Society, September 17, 1960.

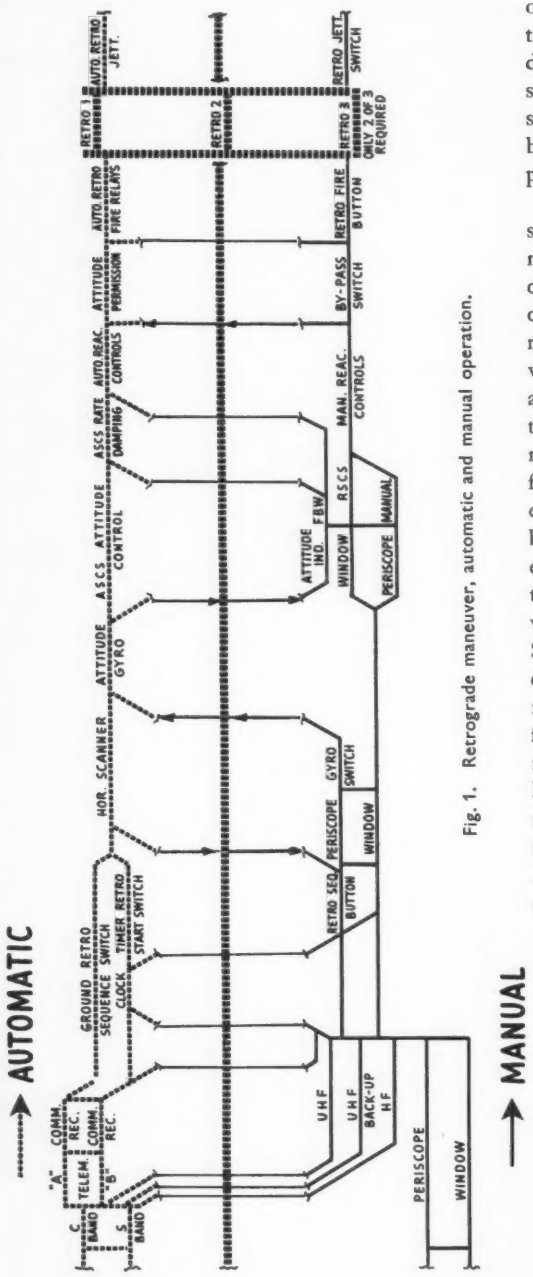

Fig. 1. Retrograde maneuver, automatic and manual operation.

one system exists for accomplishing a given task. Thus, achieving retroattitude is dependent upon correct function of the automatic stabilization and control system (ASCS). If this system does not function, retroattitude cannot be achieved and the mission will be compromised.

When man is added, a number of redundant systems come into play. Retroattitude may now be achieved not only by the automatic control system, but also by three manual control systems using fly-by-wire, rate command, or proportional manual control. Thus, whereas, without man a single method of achieving a mission requirement existed, with the insertion of the man into the system, three new methods or a total of four partially or fully redundant systems are available. Other examples of the multiple redundancies provided by the crew can be seen on the diagram. For example, in determining time for retrofiring, the astronaut has four communication channels with the ground to receive time information. Should communications fail, he has two external reference systems for determining retrotime. He can achieve retrofire in the following ways: setting the clock, starting the retrosequence, and directly initiating retrofire. Retrofire is only one example of the additional redundancies and, therefore, of the reliability achieved through the action of the astronaut. At nearly every point in the sequence, the astronaut has override and backup capability.

Except for guidance control over the booster, the astronaut has control over all aspects of the mission.

CREW SPACE AND INSTRUMENT PANEL

As background to a discussion of the pilot's tasks during the flight, a brief review of the general layout of the crew space and the instrument panel will be helpful. Fig. 2 gives a sketch of the astronaut in the Mercury capsule. In his full pressure suit, he sits in a molded couch. Approximately 27 in. in front of his face is the Mercury instrument panel.

Just above the panel is a small window giving a view out of the capsule which is similar to the normal aircraft wind screen view, with the exception, of course, that the astronaut is looking backward rather than forward along his flight path. Centered in the instrument panel is the display from the periscope which looks out the base of the capsule and gives a nadir view of the earth directly below the capsule. To the astronaut's left is his survival pack; to his right, storage facilities for water, food, and waste; slightly forward of this is the emergency egress hatch. Capsule lighting is provided by fluorescent tubes to the side and above the astronaut's head. On the left side of the main instrument panel is a large fuse panel with 23 fuses. In this area also is the storage position for the emergency flashlight and a hooked stick used to extend the astronaut's reach, should pressurization interfere with his mobility to the extent where he could not reach one of the rings or buttons on the panel.

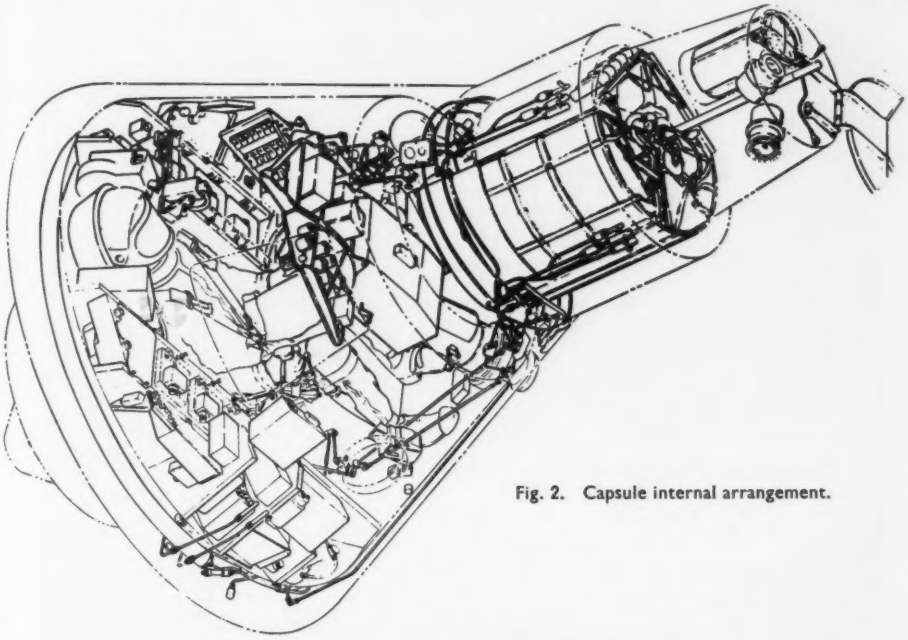

Fig. 2. Capsule internal arrangement.

Next a view is given of the instrument panel itself (Fig. 3). This panel is seen to embody some traditional aircraft concepts and some novel display systems. As in conventional aircraft, the flight instruments occupy the center of the panel. The colored panels divide the instruments into functional units: attitude control, launch and re-entry sequencing, environmental control system, electrical system, communications, and the enunciator panel. The panel contains 35 indicators, 38 lights, 57 electrical and 34 mechanical controls. In addition to these displays, the astronaut has two external viewing systems: the window and the periscope. Finally, the astronaut must make use of miscellaneous cues such as sound, vibration, acceleration, heat, and pressure changes which provide indications of system function.

This panel is the result of considerable study by the McDonnell Aircraft Corporation, the Minneapolis-Honeywell Company, and the astronauts themselves. The problems of

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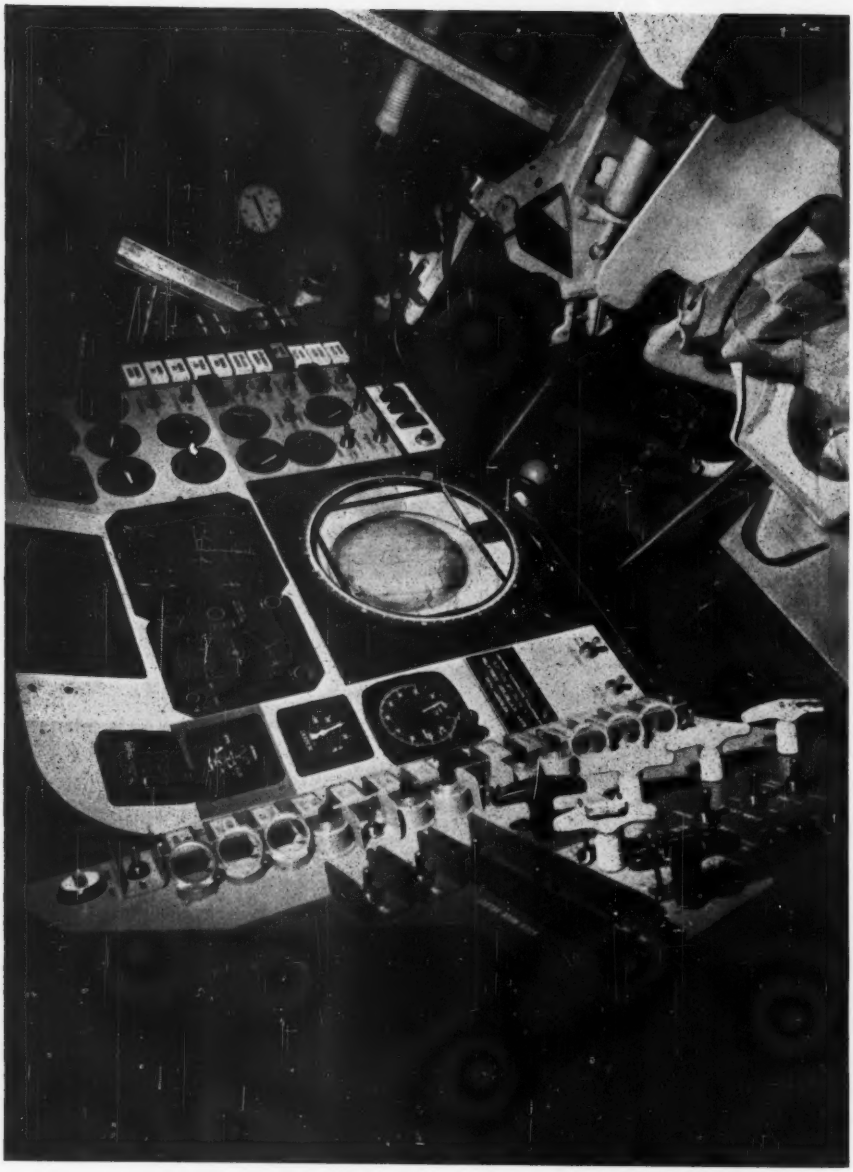


Fig. 3. Pilot's panel.

operating the vehicle in the full pressure suit have been considered by placing as many of the controls as possible to the sides and along the bottom of the panel. Rings and T-handles which permit firm gripping with the suit gloves have been used on mechanical controls. They are rotated slightly off the vertical in order to minimize the possibility of inadvertent operation of an adjacent control. As with all instrument panels, design compromises were required. Thus, all mechanical controls were required to be on the left-hand panel for structural reasons. This interfered, in some cases, with the placing of controls and displays in logical system groups.

THE ASTRONAUT'S TASKS

The astronaut performs eight basic functions during the Mercury flight:

1. The primary flight task of the astronaut can be labeled "systems management". This includes monitoring the environmental control system, electrical system, attitude control system and communications system, and in the event of a malfunction, determining the nature of the problem, its effect on the mission, and taking over manual control where necessary.
2. A second task, "programing" or "sequence monitoring", is, in a sense, a type of systems management but has a number of unique factors which make it of special interest. This activity involves the monitoring of the critical events of the launch and re-entry of the Mercury vehicle. These events such as separation from the booster, retrofire, deployment of parachutes, and such, are critical to a successful mission and involve rapid and accurate reactions to malfunction cues.
3. Control of vehicle attitude is an important astronaut task and involves a number of unique problems not encountered in standard aircraft.
4. A fourth task is navigation. The astronaut must know his position at all times, and this knowledge involves both ground reference and astronavigation.
5. An important sub-task is communications. Communications play a more significant part in the space mission than in standard aircraft operations. Through communications, the astronaut receives important navigation, fuel management, and trajectory data while keeping the ground informed of flight progress.
6. A sixth important flight task is to make research observations. A basic goal of the Mercury project is to evaluate man's capability in space. The astronaut has an important role in this research and in the evaluation of data available to him from his unique position in space.
7. To accomplish these six in-flight tasks, the astronaut must be able to keep himself in good condition under the physical stresses which he will meet. He develops and applies special skills for meeting acceleration, weightlessness, heat, and other phenomena.
8. Finally, each flight must begin with a period of ground launch preparation and countdown and must end with a period of waiting for pickup on the surface of the sea. The astronaut has many important responsibilities in these launch and recovery operations.

Systems Management

The first major area of the astronaut's activity during the flight is systems management. In order for the Mercury mission to be successfully accomplished, the four major Mercury systems (attitude control, environmental control, electrical system, and communications system) must function correctly throughout the mission. In the event of failure of one of these systems, the pilot may activate secondary or backup systems. In addition to taking action to back up these automatic systems, he must determine the effect of the failure and take proper action to modify the mission in the event it is no longer possible to accomplish

the original objectives. Systems management may become one of the most important areas of man's activities in space flight. Because of the requirement for prolonged periods of flight without access to ground support, there will be a special emphasis on maintaining the systems functions. This requirement exists of man's integration into the Mercury capsule to provide additional system reliability have been outlined in the investigations of Edward R. Jones at McDonnell Aircraft Corporation and reported in a paper presented at a meeting of the American Rocket Society, September 1959.[1]

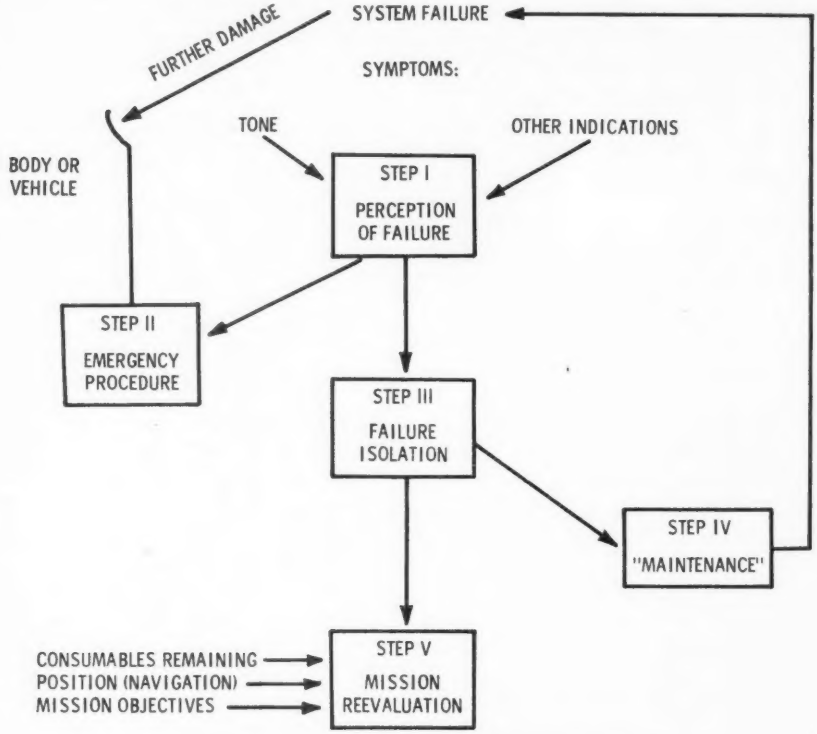


Fig. 4. Schematic analysis of systems management.

only partially in Mercury. The total Mercury flight profile of 3 orbits or 4½ hr is well within the flight time periods of current modern-day aircraft. However, even in the most dire emergency, the astronaut cannot leave the vehicle for at least 20 min. There can be no provision for bailout. Thus, Mercury represents an intermediate step between aircraft and longer life space vehicles in the requirement for basic system reliability. The basic concepts

Fig. 4 gives a schematic analysis of the astronaut's sub-tasks in systems management. The first step in the astronaut's task is to monitor capsule instrumentation carefully enough to be in a position to perceive failures when they occur. In the Mercury capsule, the most dangerous malfunctions in terms of their consequences on the mission or in terms of the difficulty for the astronaut to perceive them are set on warning systems which provide both

a tone and a light cue on the enunciator panel. The purpose of the enunciator panel is to reduce the requirement for continuous vigilance. Following the perception of the failure the astronaut may take an immediate emergency action to insure that he and the vehicle are safe from further damage or deterioration due to the system malfunction.

Certain failures may tend to incapacitate the astronaut, without his being aware of the malfunction. An example of this type of failure would be a reduction in the partial pressure oxygen in the cabin and suit circuits. This would be signaled by a tone and light on the enunciator panel. An appropriate emergency procedure in this case would be to close off the suit circuit from the cabin and go onto direct oxygen flow. This would guarantee sufficient breathing oxygen to the astronaut. However, this procedure requires a high usage rate of oxygen. Consequently, if the problem which was producing the reduction in oxygen partial pressure could be isolated and the suit system purged, it might be possible to return to the normal environmental control system.

Thus, the emergency procedure attempts to block any further damage to the vehicle or to protect the astronaut. It guarantees that the man and the vehicle are, for a period at least, in a safe condition. It allows time for the next step in the astronaut reaction to a system malfunction. This third step is the isolation of the failure which has occurred. It is not necessary, of course, that the man determine the exact component which has failed. Instead, he is interested in what functions have been lost and to what extent or under what conditions he can return to the primary system. Once the failure has been isolated, it is possible to take an action which permits return to the primary system. This step may be termed "maintenance". The term maintenance is used in a very broad sense. This use is justified because in-flight system maintenance should not necessarily be limited to equipment that can be pulled out on the workbench and disassembled. In-flight maintenance may be more generally conceived as restoring malfunctioning primary systems, by whatever means this is accomplished.

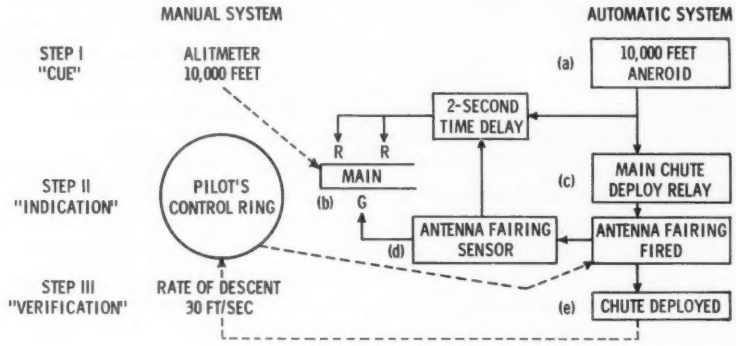
Such corrective actions in the Mercury vehicle are, of course, extremely limited. This restriction has led to a question as to whether failure isolation is a significant requirement. There is, however, another strong requirement for failure isolation. Even if it is impossible to correct a failure and thus to return to the primary system, it may not necessarily compromise the mission itself. In some cases, sufficient redundancy is provided, so that secondary systems can carry out the full program of the Mercury mission. In other cases, failures which have relatively little effect, at the moment, may have great significance for the mission success at some later point in the planned operation. For this reason, it is important to isolate the failure as carefully as possible so that step five, the mission re-evaluation, may be carried out. This involves determining the effect of the failure on the mission. In re-evaluating the mission status, certain other factors come into play: the remaining quantities of various consumables; the present position of the capsule and predicted time to a normal landing point; and finally, the overall operational objectives. If, on the basis of this analysis, a change in the flight program is required, then the astronaut goes on to take the necessary steps to initiate early retrofire and re-entry. In all these steps, he co-ordinates his activities with the Mercury range stations, where possible, receiving the benefit of the analysis and advice of systems specialists on the ground.

Sequence Monitoring

During the Mercury flight, a series of events take place which must be carefully programed to occur in correct sequence and at the proper time. During the launch, the escape tower must be jettisoned when no longer needed; the capsule must separate from the booster.

On return from orbit, the retrofire maneuver must be carried out, the retrorockets jettisoned,

the autopilot properly programed, parachutes and impact bag deployed. All of these events are controlled by automatic sequencing systems. To permit the man to back up this programing system, a set of display lights for each major event in the launch and re-entry sequence has been placed on the left-hand section of the instrument panel. Associated with each light is the astronaut's manual override. The basic concept of this light system is that a red light will come on in the event that the item is due manual programing systems for deploying the main parachute are contrasted. The main "chute" telelight is illuminated from behind by two red and one green bulb. Let us look at the mechanism for lighting these bulbs. The sequence begins with twin 10,000-ft aneroids which send a signal to a 2-sec time-delay unit and to the main chute deployment relay. A circuit through this 2-sec time-delay unit will light the red lights on the main panel unless the signal that the chute is being deployed



ILLUSTRATIVE FAILURES

(a) NO LIGHT - FAILURE
(b) NO LIGHT - PROPER FUNCTION
(c) RED LIGHT - FAILURE
(d) RED LIGHT - PROPER FUNCTION
(e) GREEN LIGHT - FAILURE

Fig. 5. Schematic analysis of sequence monitoring.

but has failed to be activated by the automatic system whereas a green light will come on if the automatic system has functioned correctly. The intent of this arrangement is that the man should make a response in the presence of the red light and no response in the presence of the green light. Stated in these terms, the task seems to be a simple one. However, a deeper analysis of this aspect of the astronaut's job indicates that such an assessment is misleading.

If the man is to carry out this task, he must substitute himself for the malfunctioning automatic programer. In Fig. 5, the automatic and comes back within that time. The signal to the main chute relay permits a signal to go to fire the antenna fairing. Antenna-fairing separation is sensed by the antenna-fairing sensor which in turn sends a signal back to the 2-sec time-delay circuit, blocking the lighting of the red lights. It also applies a voltage to the green light. The antenna fairing pulls the main chute with it.

It is interesting to note the effects of various malfunctions on the astronaut's display. If the system failed at the 10,000-ft aneroids (labeled (a) in the diagram), then no signal would come

from this unit and the light would not light either red or green and the chute would fail to deploy. In case (b), where the green bulb fails to light, the pilot would get the same indication, that is, no light; but the automatic system would perform correctly and deploy the chute. If the main chute deployment relay malfunctioned (case (c)), then the failure warning would work as intended, namely the red lights would light and the chute fail to deploy. If, however, the failure were in the antenna fairing sensor, a red light indication would be obtained but the chute would deploy. If the chute deployed, but streamed, as in malfunction (e), then a green light could come on, on the main panel, but failure of the main chute system would still occur. Thus, it is possible to get no light and have a failure; to get no light and have a proper function; to get a red light and have a failure; to get a red light and have a proper function; to get a green light and have a failure as well, of course, as the most probable event having a green light and proper function. Now, the probability of any one of the malfunctions involved here is very low, just as the probability of failure of the whole system itself is low. However, while the probability of malfunction of any given component is very low, because there are such a large number of units in the many systems which make up the Mercury capsule, a significant possibility of malfunction remains. It is the function of the man in this system to take over in the event of such malfunction and substitute himself for the automatic system. From the example outlined here, it can be seen that in the sequencing system, it is not possible to rely entirely on just the color of the sequenced light. The fact that instruments may sometimes be untrustworthy is certainly no novel finding for anyone familiar with aircraft or even with the automobile. However, it is often possible to overlook the full performance requirements when describing the task only in terms of the external signal immediately available to the pilot.

In order then to carry out this sequencing function effectively, the pilot must be his own programer. This is illustrated by the manual system outlined on the left-hand side of Fig. 5. This manual programing system can be analyzed as a three-step procedure for each item in the sequence. The first step is obtaining a cue as to when a given sequence item action should occur. In the present case, the altimeter indication of 10,000 ft provides a cue that the main chute should be deployed. The next step is to check the main chute telelight to see that the automatic system has functioned. He can then verify the indications given him in the telelight by checking the rate-of-descent indicator which should fall to 30 ft/sec. If, on verification, he finds that the automatic system has failed to deploy the chute, he has the choice of using his own pilot control ring for the main chute or if there is an indication that the chute was deployed but did not open properly, he could jettison that chute and deploy the reserve by using the pilot's ring on the reserve chute.

This schematic representation of the manual sequencing process is oversimplified, of course. The pilot has other cues than the rate-of-descent indicator with which to verify deployment of the main parachute. Most effective will be his own visual inspection of the chute, using the window or the periscope. It does serve, however, to emphasize the total process of pilot's activity at this time. He is attempting to get cues for the initiation of critical events by use of his flight instruments, such as the accelerometer, altimeter, rate-of-descent indicator and clock. He is checking his sequence panel for indications that the automatic programer is working properly. Finally, he is verifying the action of the automatic system or his own manual override action by use of flight instruments, external vision, sound or acceleration cues.

Attitude Control

Since the launch is automatically programed through the Atlas or Redstone boosters, the pilot has no attitude control problem while

attached to the missile. When the capsule is in orbit and during the re-entry, attitude may be controlled by either the autopilot or the astronaut. In controlling the attitude of the Mercury capsule, the astronaut may encounter four basic types of problems: controlling attitude in orbit; controlling attitude during retrofire; rate damping during re-entry; and recovery from tumbling maneuvers. Controlling attitude in orbit is a relatively simple problem, as long as high accuracies are not required. Unlike aircraft operating within the atmosphere, the attitude of the vehicle itself does not influence flight path in orbit, as long as secondary power is not being applied. In most cases, rapid actions will not be required. Slow movements to get into position will be satisfactory.

The second type of problem faced in Mercury attitude control is maintenance of attitude during retrofire. This is the most difficult of the attitude control problems. During the retrofire maneuver, the astronaut must hold the position of the capsule within certain tolerances in order to get the full value of retrofire. The retrorockets will be aligned so that the force vector will pass through the center of gravity of the vehicle. However, due to the use of consumables and other factors, the retrorockets may not be perfectly aligned at the time of retrofire. In this case, they will produce torques about the major axes of the vehicle, particularly in the yaw and pitch planes. These torques develop rapid rates of motion about the axes which must be controlled by the astronaut.

A third attitude control problem is re-entry rate damping. The Mercury vehicle is statically stable on re-entry, at all Mach numbers. However, during re-entry, the capsule may experience oscillation about the re-entry attitude. Large oscillations may produce excessive heating on the vehicle afterbody. The astronaut, in the event of the failure of the automatic system, must damp these oscillations. In applying damping, he concerns himself only with vehicle rates. This is in contrast to the information required in a lifting re-entry vehicle, where the astronaut would be controlling the vehicle attitude on re-entry in order to make use of lift to reduce acceleration and heating.

A final problem is recovery from a tumbling maneuver. It is possible that on separation from the booster, the capsule may receive a torque which causes it to tumble. This may cause gyro gimbal lock or tumbling, which will result in the attitude indications being inaccurate. The rate indicators, however, will not be affected by tumbling and will give an accurate indication of the movement about the three axes of the vehicle. In this situation, the astronaut brings his rate to zero and then can manually erect his gyros.

To perform these tasks the astronaut has available to him three manual attitude-control systems, in addition to the basic automatic control system; a "fly-by-wire" system, which works through the autopilot; a direct manual system, which works through mechanical linkages to the manual control fuel valves; and a rate-command system which also uses the manual fuel system, but which has a logic circuit to provide rate damping. The astronaut also has three basic display systems: his instruments, which include a rate and attitude display; a periscope, which permits ground viewing and determination of the earth vertical; and a small window, which provides a view of the earth's horizon.

Experience with this control system has uncovered a number of interesting problems for the Mercury astronaut. In using the reaction controls, which are acceleration controls in a frictionless environment, the importance of a rate display is greatly increased. Thus, on the Mercury panel, the three rate needles occupy the central position in the instrument group. During the most difficult attitude control task, retrofire, the rate indicators are the primary reference for the pilot. He cross-checks against attitude indicators, making corrections when these show variation from the retroattitude. However, most of the control actions are taken

in response to changes on the rate indicators, which give him the most immediate indication of the effects of retrorocket fire. During the re-entry rate-damping task, the attitude indicators are inoperative, and he has only rate information. For the least demanding of the three tasks, attitude orientation in orbit, the attitude indicators become the primary instrument, particularly where the maneuver is carried out in only one axis, as is usually possible. However, increased fineness of control is possible, through reference to the rate indicators. As described previously, the rate indicators also play an essential role in the recovery from a tumbling maneuver.

The attitude control problem is affected by a number of sources of coupling. It is difficult to operate the three-dimensional hand controller without some cross coupling between axes. Further, the manual reaction jets are slightly out of line, which produces a small amount of coupling between axes. Most important is the apparent coupling on the instrument display when the vehicle is in an unusual attitude. Since the attitude gyros are fixed in reference to the earth, if the vehicle pitches up 90°, the yaw and roll axes will appear to be interchanged on the attitude indicators.

External attitude reference also presents some special problems. Through the window, the pilot will get a typical wind screen view of the earth, which should provide good roll and pitch reference, as long as the horizon can be discriminated. It is possible that on the dark side of the earth, in the absence of the moon, the horizon will be difficult to see. Yaw reference will be a more difficult problem than on aircraft, because the rapid rate with which the terrain moves below the vehicle does not permit the use of a landmark as a heading reference. On the other hand, the drift rate as seen from the vehicle is not rapid enough to provide a good yaw reference. Moreover, the use of drift is complicated by the lack of patterning when over water, clouds, or the dark side of the earth. In addition, small residual pitch and roll motions can easily be confused with drift. Probably the most valuable yaw reference will be the stars as seen through the window, since they will remain fixed in yaw relative to the capsule's orbit. The primary question with regard to use of stars for reference will be their visibility, particularly on the daylight side where strong light from the sun and reflected light from the earth may interfere with viewing out the window. Like the window, the periscope provides relatively good reference for pitch and roll control. But determination of yaw must be based on measured drift. Since much of the orbit will be over clouds or water, without patterned objects which can be used to determine drift, yaw reference through the periscope may be difficult. Also, it should be noted that since the periscope will reduce the image of the earth by a factor of 9, roll and pitch rates as perceived through the periscope will be 1/9 of those indicated by the instruments or seen through the window. Another problem that arises in adapting to the use of the periscope is a slight initial confusion between yaw and roll. Being used to wind screen view of the earth, the astronaut tends to interpret circular motions as being due to roll. However, since the periscope looks normal to, rather than parallel with, the earth's surface, rotational motions are actually yaw rather than roll. This has been an initial source of confusion in using the periscope on early training efforts.

Navigation

The astronaut should have a good knowledge of his position at all times. Two specific navigational requirements for the astronaut can be noted. The first and most essential of these is for impact-point prediction and control. The vehicle in orbit is moving at approximately 5 m.p.s. The normal recovery zones, at the end of each orbit, are approximately 150 miles in length. Since the nominal impact point will be in the center of these zones, an error of ± 75 miles will place the capsule outside the

primary recovery zone. At 5 m.p.s., the 75 miles is equal to a 15-sec error. The second requirement for astronaut knowledge of the capsule position is to facilitate communication with ground stations and observation of predetermined check points. Contact with monitor stations will vary between 2 and 5 min. For the shorter station passes, the astronaut will be required to be alert and ready to communicate. Since the possible contact is so short, an error by the astronaut in estimating his estimated time of arrival (ETA) at the station could result in a failure to contact that station. In addition, terrain features of special interest and ground check points will be designated in advance. Failure to predict the ETA correctly over these areas might result in his missing valuable observations.

The position of the capsule at any time can be calculated from the nominal trajectories. The astronaut is provided with a map on which elapsed time since launch is marked along the orbit tracks in minute intervals, permitting the astronaut to determine his estimated position by referring to the elapsed time clock. By interpolation, the astronaut may achieve an accuracy of approximately ± 15 sec. If the capsule achieves the nominal trajectory, the ETA over any given point should be calculable within 15 sec. Given this trajectory and an accurate clock, the astronaut should be able to time the retrofire accurately enough to reenter within one of the primary recovery areas. In actual operations, the astronaut would not attempt to read the retrotime off his map, but would carry with him the retrotimes for each of the primary recovery areas. If the capsule were on the nominal trajectory, the exact retrotime could be set into the clock. The primary navigational problems arise, then, when the capsule trajectory deviates from the nominal trajectory. In this case, the astronaut must first determine the extent to which the trajectory is deviating from the nominal trajectory and then adjust retrotime accordingly.

Three methods are available to the astronaut for updating the nominal trajectory. The primary and probably the most accurate method, assuming proper function of the complex range system, would be the ground-computed position. This system depends upon radar trajectory data from the launch site and from other radar sites around the earth, which are transmitted to a central computer facility. On the basis of this information, the computer will provide an accurate retrotime in terms of elapsed time. This information must be transmitted over the range communications network and then to the astronaut. Should all components of this system function correctly, it should provide a high level of accuracy in computing the specific retrotime. It is dependent, however, upon a rather complex system of communications between the capsule and the ground and between stations on the ground.

A second method for the astronaut to update the nominal trajectory is by use of ground reference. Through the capsule periscope, the passage of ground check points directly below the capsule can be timed. From these ground fixes, the nominal orbital data may be modified. The use of ground reference depends upon (1) good ground visibility, (2) proper alinement in attitude, and (3) an accurate clock. These factors are discussed in more detail below.

The third method of correcting the nominal trajectory is through celestial reference. By use of scribe lines on the capsule window, capsule position can be determined by reference to the celestial sphere. This method depends upon (1) visibility of the constellations of the zodiac, (2) proper attitude orientation, and (3) an accurate clock.

Of the three factors affecting the astronaut's determination of position from external fixes, the accuracy of the capsule clock should provide the least error. The clock is being fully qualified for the conditions expected during the flight and over the launch, and a short period of time should not cumulate significant errors. The problems of external visibility from the capsule have been discussed in some detail by Edward R. Jones of McDonnell Aircraft Corporation

in a paper presented before the Aerospace Medical Association in May 1960.[2] Factors affecting ground visibility will be the amount of cloud coverage (perhaps as high as 50 per cent or more) and the light available. On the daylight side of the earth, there should be plenty of illumination in which to see ground reference points. However, on the dark side, it may be so dark that the ground check points cannot be distinguished. In addition, the large water areas of the Pacific and Indian Oceans may not provide recognizable check points. Ground visibility status will be affected by external and internal lighting conditions. On the light side of the earth, the sun and the reflected light from the earth's surface may provide so much contrast that the stars become invisible. Further, the requirement for structural integrity and for the reduction of reflections due to internal light on the capsule window have resulted in a window design which greatly reduces the amount of light transmitted with the result that the visibility of the stars will be greatly decreased. In addition, unless dark adaptation can be maintained on the light side of the earth and the capsule lighting dimmed, the visibility of stars, even on the night side, may be somewhat limited.

The third problem, attitude control, greatly favors use of ground check points as compared to the use of the celestial sphere as a reference. The autopilot will maintain the capsule attitude within $\pm 3^\circ$ about the three axes of the vehicle. The effect of such errors is smaller in the case of ground check points than in the case of star reference. An error of 1° in maintaining the earth vertical would result in less than a 2-mile error at an altitude of 100 miles. On the other hand, the same amount of error in reference to a star amounts to approximately 60 miles at the equator. Since the capsule is traveling at approximately 5 m.p.s., the error due to vehicle attitude is within the reaction time error of the astronaut, since it is unlikely that he can time the arrival at a check point to an accuracy greater than 1 sec.

Communications

Through the medium of communications, the complex systems which make up the total Mercury mission must be integrated. Critical units of the launch range and recovery systems are the blockhouse, booster-guidance systems, the Mercury range which consists of a central control station, 13 range stations, and a computer center, and finally the recovery units. The astronaut communicates with the blockhouse and central control prior to launch, with the 14 range stations during the flight, and with the recovery forces in his area following the flight. The range sites are situated around the world in such a position that the astronaut will be able to communicate with one of these stations approximately 50 per cent of the time he is in orbit. The longest period between stations is 20 min.

Through this range network, the astronaut receives 7 basic types of information. During the launch, he receives information on the booster and the capsule trajectory. This communication is essential since the astronaut has no immediate information on the booster status. The ground informs the astronaut on the progress of powered flight and informs him immediately of any problems with booster or ground guidance. The second type of information from the ground is for the purpose of providing sequencing cues. During the launch and re-entry, the astronaut can be given an indication when certain important events such as tower jettisoning, separation, and chute deployment should occur. These data can be based on ground time information or ground trajectory information.

A third function of the ground system is to provide the astronaut with a backup in the area of systems monitoring. Generally, the astronaut has more complete information on the function of the vehicle system than the ground personnel; however, it is possible that he may fail to note an indication of a malfunction. Moreover, in some cases, the ground monitor has information not available to the astronaut. In these cases, the flight controller

is able to feed additional data to the astronaut for evaluation. Finally, based on the astronaut's description of events in the capsule, together with telemetered data, engineers on the ground may be able to advise him as to the probable malfunction.

Fourth, the astronaut receives medical information on his physiological status. On the ground, the flight surgeon has available to him telemetered heart rate, respiration rate, and temperature. These data, of course, are not available to the astronaut. The astronaut's subjective feelings may not be reliable, particularly under the conditions of the flight; therefore, the medical monitors are in a position to alert the astronaut, should there be an indication that a medical problem is developing.

A fifth function of the ground personnel is to maintain graphs of the major items of consumables aboard the capsule, such as fuel, cooling water, oxygen, and so forth. These plots are based on telemetered data, together with confirmed reports from the astronaut, and can be evaluated by ground personnel to determine that the rate of use of these items is as programed. Sixth, the ground services provide information on the weather, the recovery ships, and the status of the range. The weather information is critical, not only because sudden changes in weather status might make re-entry in one of the planned areas undesirable, but in addition, because the weather will control the observations the astronaut can make and his ability to make ground checks for position. The status of recovery ships may also influence his choice of re-entry point, while the status of the range stations may determine where he will be able to communicate. Finally (seventh), the communications to the pilot serve the purpose of updating his time and navigation information. The pilot will begin navigation, based on the nominal trajectory. Based on the actual insertion parameters, range personnel will be able to inform him of deviations from the nominal trajectory, which should permit the astronaut to determine his position more precisely.

In addition to these items of information, which are sent to the astronaut, the astronaut sends to the ground data in four areas. First are the reports on such items as his own status, his subjective feelings, and his apparent well-being. Second is information on the capsule systems status as he sees it. This area includes information on such things as what mode of control he is using, whether he is on primary or secondary systems, and similar data. In addition, he will report the instrument readings on critical parameters such as fuel and oxygen quantities, in order to verify and cross-check against ground telemetry data. Thirdly, he reports the mission status as he understands it. He reports his position, based on his own navigational fixes, his retrotime, the status of his planned program of activities, and so forth. Finally, he reports on the observations he is making, both of himself and his own performance, the vehicle and its performance, and of the external environment.

Three critical decisions can be made by using communications. First, the astronaut, in concert with ground information and ground advice, may determine what corrective actions are to be taken in a given situation. Since the astronaut has the most complete information on the vehicle systems, most corrective action will result directly from his own knowledge of the vehicle and the information directly available to him. However, in some cases, information and advice from the ground may play an important role in taking corrective action, particularly where medical information which is not available to him plays a role in determining the need for action. A second critical decision that is made through the communications is the "Go–No Go" decision just prior to the insertion of the capsule in orbit. If an abort is to be made because of the capsule status, it must be made prior to burnout of the sustainer stage, in order to return the capsule in the Atlantic Ocean. Thus, a positive decision is required just prior to burnout, that the capsule and the astronaut are in condition to be inserted in orbit. This

decision is made by the ground flight controllers and the astronaut. A final decision area is the decision to terminate the mission. The mission will normally terminate at the end of three orbits. However, if malfunctions develop or if range conditions do not permit recovery in the planned third orbit area, an earlier recovery may be necessary. The decision of where and when to terminate the mission is a critical one, requiring precise information on the required time for retrofire. The decision to terminate the mission will require maximum coordination between the astronaut and the range.

In-flight Research

Research and evaluation programs which involve the astronaut can be divided into four general categories. First, the astronaut will be required to make evaluations of the vehicle function and performance. This is the traditional job of the test pilot. He reports to the ground indications of the vehicle's performance, particularly in areas where telemetry or onboard record systems are not providing measurement. He also investigates maneuvers which are not provided for in the automatic programing of the system, thereby evaluating the system under unusual conditions which can more fully test its capabilities. A second role of the astronaut is to observe the space environment in which he travels, including the heavenly bodies and the earth below him. In this, he attempts to bring back information which will be valuable to earthbound scientists in such areas as astronomy, meteorology, geophysics, and so forth. Thirdly, by submitting to physical examination before and after the mission, by reporting on any medical symptoms which he may experience, and by allowing medical personnel to draw blood and urine samples, he provides medical data for analysis of the human physiological responses to the space environment. Finally, by performing his in-flight activities, such as monitoring the vehicle systems, making voice reports, controlling vehicle attitudes and in certain cases, doing special performance tasks, he provides data on which his performance capability can be evaluated.

Physical Stress Management

During the flight, the astronaut will be exposed to acceleration, reduced pressure, heat, vibration, noise, and possibly such abnormal conditions as tumbling and high levels of carbon dioxide. If he is to perform the tasks described previously, he must be able to react appropriately to these stresses. He must be sensitive to these conditions to the extent that they provide cues to system function during the mission. At the same time, he must not allow them to divert his attention from his flight task. In some cases, there are specific skills in the management of these stresses which can be learned and practiced. For example, to minimize the grey-out and the sub-sternal pain due to the transverse g, the astronaut can make use of a straining technique. This technique can be learned by centrifuge training and must be consciously exercised. In addition, through the somewhat subtler changes produced through repeated exposure to the physical conditions of the flight, an adaptation to these stresses can be achieved which will maximize his resistance to performance decrements as a result of exposure to them. He must learn to regulate his behavior and activity level so that he does not overly fatigue himself when in the full pressure suit. During the re-entry and the postlanding heat pulse, he should remain as quiet as possible so as not to generate extra heat to complicate an already difficult cooling problem. Thus, the astronaut must be more aware of his own function and its inter-reaction with the environmental control system which supports him. He must develop the skills and knowledge which are required to work effectively within this more limited environment without taxing himself or overloading the environmental system.

Ground Tasks Associated with Launch and Recovery

The astronaut has an important role in the preparation of the vehicle for the flight. The

Mercury capsule will arrive at the launch site at 6 to 8 weeks prior to the launch date. During this period, the capsule will be mated to the booster, and checks of the capsule systems and the compatibility between capsule and booster systems will be made. Many of these checks will require that controls within the vehicle be operated. It is desirable, both for training and for proper equipment checkout, that the astronaut take part in these activities. During the countdown, he will observe and aid in the preparation of the vehicle. He will communicate with the blockhouse and participate in that part of the countdown associated with the checkout of the vehicle and astronaut system.

After the astronaut returns to earth and lands in the water, he must wait for pickup for a period from 30 min to several hours, depending on the accuracy with which he has been able to return to a planned recovery area. In the unlikely event that he should have to abort and return outside a planned area, the delay in pickup might be even more prolonged. The astronaut, therefore, must be able to survive in the water, either in the vehicle itself, or if that should prove to be untenable, in his life raft. In the unlikely event that he comes down on land, he must be able to survive in tropical or desert areas for prolonged periods and to aid in his recovery by using various signaling devices.

Non-flight Tasks

It should be noted that there is a second major category of astronaut activities which has not been covered in this discussion; these are the non-flight tasks. The glamorous part of the astronaut's job, the function which catches the most attention, is, of course, the flight itself. While this is the focal point of the astronaut's activities, it is generally not recognized that the astronauts have duties and functions outside of preparing themselves for the flight. One of these assignments is to make contributions to the design of the Mercury vehicle, crew space and astronaut personal equipment. Shortly after the astronauts reported to Project Mercury, they were given an opportunity to go to McDonnell Aircraft Corporation, view the capsule mock-up and make suggestions for the crew-space layout, instrumentation, and manual-control system. These early contributions resulted in a number of significant improvements in these areas. In addition to design recommendations, the astronauts have, on occasion, participated in design studies. The best procedures for the protection of the man against acceleration, the design of the hand controllers, and other factors of this type require design studies to which the astronaut can contribute by being a subject under test.

In addition to his contribution to systems design, the astronaut can aid in system development by being available for fitting and integration with the vehicle components. For the Mercury vehicle, a special couch must be molded for each man. The mounting of the couch within the capsule varies for each man in order to give him an optimal viewing distance from the instrument panel. In addition, pressure suits must be individually fitted. These special fittings require considerable lead time in themselves. Since the number of individuals who will have an opportunity to make space flights in the near future will be very limited, it will be both feasible and desirable to tailor the crew space to the individual as much as possible.

As hardware comes off the production line, a test program must be initiated to qualify the equipment. For adequate evaluation of manual systems, a human operator is often required. While these evaluations can and in certain cases should be made by using engineers or technicians, it is desirable to make at least some of them with the astronauts themselves in order to take advantage of their special knowledge of flight problems, and where possible, to meet their specific requirements. The astronauts also aid in the Mercury program by contributing to the development of operational procedures for the vehicle, the launching site, and the range. While they came to

Mercury with little practical experience with missile technology, all have had extensive operational experience with aircraft. Much of this knowledge can be applied to Mercury operational problems.

In addition to these engineering tasks, the astronauts make an important contribution in the dissemination of information to the public. It is a truism that people empathize with other people better than they do with machines. The public's attention tends to be focused on the astronauts because it can better understand their feelings and reactions than the technical aspects of the hardware. Thus, while an attempt is made by NASA to minimize the demands on the astronauts in this area, they play an important role in interpreting Project Mercury to the public.

CONCLUSIONS

In conclusion, some of the major principles growing out of experience with the Mercury astronaut's task may be re-emphasized. This experience suggests that the most unique feature of space vehicles will be the requirement that they operate continuously for relatively extended periods of time without access to ground maintenance facilities. Not only must they function for extended periods of time without extensive maintenance to accomplish their mission, but in the face of a serious malfunction, they must still have backup systems which can operate successfully for somewhat shorter but still lengthy periods in order to safely return the man to the surface of the earth. Because of the limitations in the present state of the art of engineering, insuring this type of reliability is difficult, perhaps impossible, without man. The astronaut can make his greatest contribution by detecting malfunctions and taking corrective actions to overcome them. Thus, the vehicle operator must take on much of the maintenance function that has formerly been delegated to ground crews. It appears likely that for long-term flights, this will become a more critical and difficult area for the vehicle operator than the more traditional tasks, such as attitude control, power management, and communications.

A corollary of the role of the astronaut in increasing reliability is that he will often have to make use of less than optimal controls. Man's efficiency in controlling attitude, as an example, can often be improved by "rate aiding" or "quickening" or by power boosting the controls, and so forth. However, each of these auxiliary systems is dependent upon power and electrical or mechanical components which can malfunction. To the extent that man is dependent upon complex systems in order to make his inputs, his total contribution to reliability will be reduced by the unreliability of these components. In the past, when the operator could be supported by a large ground maintenance facility, it was often desirable to maximize his performance for the critical moments of flight at the cost of greatly increasing maintenance complexity. For space flight, where the operator must also do the maintenance, the trade-off may well be in favor of using simpler systems which require less maintenance and are more reliable, even at the cost of somewhat reduced proficiency in task performance.

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Perceived Movement in Depth as a Function of Luminance and Velocity

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The ability of subjects to perceive movement in depth of a luminous object in an otherwise stimulus-free surround has been studied. This research resulted from an analysis of anticipated visual skills required in certain manned space vehicle operations. This stimulus object subtended a visual angle of 40 min of arc at the onset of movement. Luminance was varied from 0.001 to 1.0 ft-Lambert. The speed of movement was varied so that the change in visual angle of the stimulus varied from approximately ¼ min of arc per sec to approximately 2 min of arc per sec. Both monocular and binocular viewing conditions were used. Detection of movement improved as the luminance increased from 0.001 to 0.1 ft-Lambert. A further increase in luminance to 1.0 ft-Lambert did not affect performance significantly. Rate of movement interacted with the threshold criterion level; the higher rates of movement were superior for the higher threshold criteria. Binocular viewing was superior to monocular. Under optimum conditions 75 per cent correct detection was achieved when the visual angle increased or decreased by 2 per cent.

INTRODUCTION

The purpose of this paper is to examine the nature of certain visual skills which might be required in manned space operations. Of particular interest are the visual tasks involved in the assessment of the relative movement in depth. The assessment of relative movement in depth is a critical aspect of the task involved in effecting a rendezvous in space by direct visual sensing.

Smith[3,4] reported thresholds for the detection of angular subtense change (apparent movement) and found that sensitivity to apparent movement, as measured by response time, was unrelated to object shape or to apparent three-dimensionality of the object. Two studies indicated that binocular viewing was superior to monocular in perceiving apparent movement in depth.[4,5] It was further found that luminance, but not apparent size, had an effect on response time.[5] The present study was designed to extend the range of luminance previously used and to vary the rate of actual movement in depth. The method of constant stimuli, in which the stimulus moved away as well as toward the subject, was used in order to avoid the inherent difficulty of controlling a subject's criterion which is associated with the method of limits used in the studies referenced above. The data presented are intended to assist in the determination of man's ability to perform the sensing, by visual means, required for terminal navigation in soft-contact rendezvous with another satellite in space.

THE VISUAL ENVIRONMENT IN SPACE

At a 300-mile orbital altitude, with relatively free access to direct visual observation through a 360° sphere, the Earth will occupy about one-third of the total visual environment; and the remainder will be space with its stars, planets, the Moon and the Sun. The general appearance of the stars, planets and Moon will not be significantly different from that on a clear night at the earth's surface. However, those portions of the Earth illuminated by the Sun will vary greatly in intensity depending on the albedo or reflectivity of the illuminated areas. Cloud covered areas or terrain covered with snow will have a luminance of almost an order of magnitude greater than the luminance of a full Moon; and depending on the relative angular position of the Sun, sea areas will range in luminance from extremely intense "high spots" as a result of specular reflection of the Sun to large, very dark areas.

If we assume that an object to be contacted

in space is not in the shadow of the Earth, the direct solar illumination on the object will be greater than 10,000 ft-candles. If the Earth below the satellite is illuminated directly by the Sun, those portions of the satellite exposed to the Earth's reflected light will themselves be illuminated under certain conditions, to a degree approximately one-half that of direct solar illumination. The satellite surface may be purposely designed to have a high reflectivity or albedo in order to maintain a desired temperature within. Thus, the satellite's illuminated surface may provide an intense visual stimulus. If this surface were to reflect incident illumination diffusely, it would have a luminance in the order of 5,000 or 10,000 ft-Lamberts. This is approximately the luminance of snow on a clear sunny day. If the satellite's surface were to have highly specular reflectance the intensities of the reflections from the "highlights" would be several orders of magnitude more intense than that from a diffuse surface. In either case, when an object is relatively near (within several thousand ft), it will constitute an extreme stimulus, the glare effects of which could render invisible those background stars in the angular vicinity of the satellite. Of course, the apparent intensity level can be reduced for the viewer by the use of high density optical filters, but the use of filters will also reduce the visibility of background stars. The important consideration for this viewing condition is that the satellite, being observed from relatively near distance, may be the only object visible if the Earth, for example, is not in the direct line of regard. Thus, it is important to know how well man can make estimates of closing rates and relative direction of movement of a satellite when viewed in this unstructured visual field.

A satellite in the shadow of the Earth can remain visible if illuminated by light reflected from the Moon. The luminance of the satellite under such conditions would be in the order of 0.01 ft-Lambert. Under these conditions the background stars and planets would remain clearly visible. Thus, the luminances that man will deal with in space extend over a considerable range and the visual environment will vary in the amount of structure.

STUDY NUMBER ONE

This study dealt with the ability of human subjects to perceive whether an object, viewed in an otherwise totally dark field, was approaching or receding when the luminance of the object and the duration of observation were varied. Both binocular and monocular viewing conditions were used.

Apparatus and procedure. The stimulus object was a circular, electro-luminescent lamp, 3.5 in. in diameter. It was mounted on a cart which traveled on tracks, either directly toward or away from the subject at a constant speed of 3.3 in./sec. The stimulus lamp was energized when the cart supporting the target crossed a microswitch. At this point the stimulus lamp was 25 ft from the subject, and subtended a visual angle of 40 min of arc. The angular subtense of the stimulus increased or decreased, depending on whether it moved toward or away from the subject, at an initial rate of approximately ½ min of arc per sec. The lamp, depending on the experimental condition, had a luminance of 0.001, 0.01, 0.1, or 1.0 ft-Lambert. The ten durations of exposure were 0.6, 0.9, 1.2, 1.8, 2.7, 4.2, 6, 9, 13.2 and 19.8 sec. Only six durations were used for a given luminance condition, the shortest six durations being used with the higher luminance levels.

Four adult subjects with several hours of training on the task were used. The experimental design was a 4×4 latin square used to counterbalance the order of the luminance and viewing conditions. Individual experimental sessions were conducted following a 15-min period of dark adaptation. Each experimental session consisted of 25 trials at each of 6 exposure durations for a given luminance and viewing (monocular or binocular) condition. An experimental session lasted about 90 min. Each subject had each luminance condition

twice for each viewing condition. This required a total of 16 sessions, each subject yielding 2400 observations.

The experiment was conducted in a light-tight room 50 ft × 20 ft with a 12-ft high ceiling. The walls and ceiling were covered with a black matte flocking material to minimize reflected illumination. During the experiment the subject was seated in a booth, his head supported by a chin rest adjusted so that he could view the stimulus object through an aperture in the front of the booth. This arrangement provided direct visibility of the stimulus object in an otherwise totally stimulus-free visual field. The subject was alerted a few sec prior to each trial presentation. The stimulus object then appeared for a controlled duration. The subject responded by moving a three-position switch to indicate whether the object appeared to approach or recede. He was not informed of the correctness of his response. A two-category, forced-choice method was used, i.e. the subject had to respond with his best guess. The order of presentation of whether the object approached or receded was selected from a table of random numbers, modified only so that each condition appeared an equal number of times. A 400-cycle converter, used to drive the stimulus lamp, was positioned near the subject. The noise level generated by this converter was sufficient to mask auditory cues resulting from the movement of the cart on the tracks.

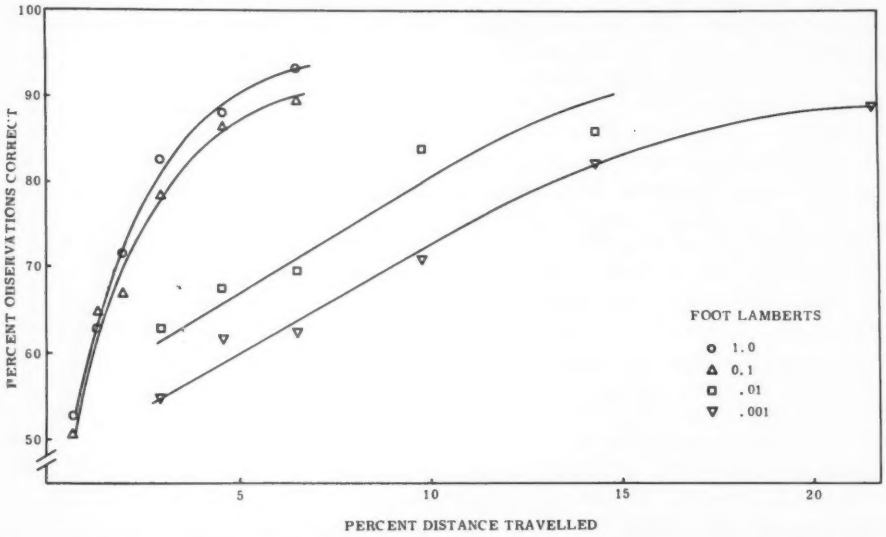

Fig. 1. Accuracy of perception of movement in depth as a function of the observed distance traveled for four luminance levels. The 50 per cent value on the ordinate represents chance performance. The curves are the average of binocular and monocular conditions. Each point is based on 400 observations, 100 by each of 4 subjects.

Results

Fig. 1 shows per cent of observations correct as a function of the per cent of the original distance (25 ft) traveled for the four luminance levels used in the study. The per cent distance traveled is directly proportional to the duration of observation and, for the range of values involved, the per cent distance traveled approximates the per cent change in visual angle subtense of the stimulus object. The curves shown are the average curves for both binocular and monocular vision. The 50 per cent value on the ordinate represents chance

performance. With no information, the subject, by guessing, would be correct about 50 per cent of the time. The data shown are the averages of the measures when the stimulus approached and when the stimulus receded. Although each condition occurred an equal number of times, the subjects reported that the object was approaching in 51.9 per cent of the

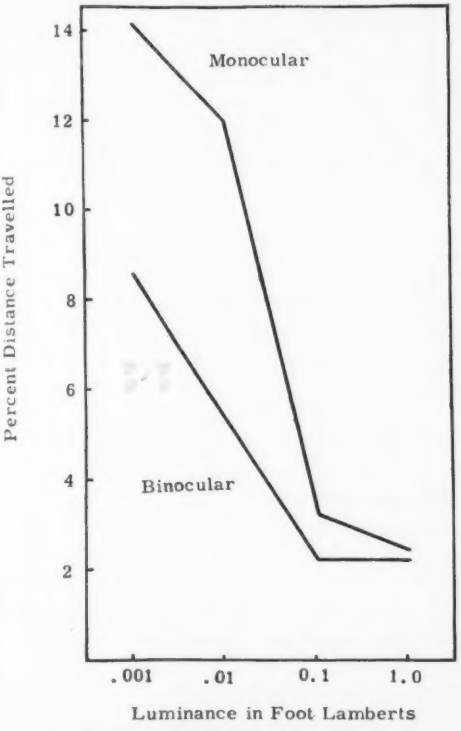

Fig. 2. The per cent distance traveled required for 75 per cent detection of movement in depth as a function of luminance level for monocular and binocular viewing conditions.

observations. This small, though statistically significant bias may indicate that when the object approached, the movement in depth was more easily perceived than when it receded. This would be expected because a slightly greater visual angle change occurs per unit time when the object is approaching as compared to receding. Also, there may have been a response preference independent of the stimulus conditions which would account for this small bias.

Fig. 2 presents the per cent distance traveled required for 75 per cent correct detection of movement in depth as a function of luminance for monocular and binocular viewing conditions. For 75 per cent correct detection, the per cent distance traveled decreases with increasing luminance up to 0.1 ft-Lambert. Further luminance increase to 1.0 ft-Lambert did not affect binocular performance and only slightly lowered thresholds for the monocular condition. The marked superiority of the binocular over the monocular viewing condition for the lower luminances is not easily accounted for. Since no other stimuli were in the visual field, disparity cues were not present and convergence cues could contribute very little, if any, information for the viewing distances involved. The only reasonable cue available for discriminating the movement in depth is the change in retinal image size in time. Conceivably, binocular summation of the stimulus energy could account for at least part of the marked superiority of the binocular condition at the lower luminance levels.[2] Smith[5] found a superiority for binocular over monocular viewing in a similar visual task. However, Smith used luminance levels in the order of the higher levels used in the present study, and at these luminance levels binocular summation of energy should contribute little, if any, improvement. An analysis of the superiority of binocular over monocular visual acuity has been reported elsewhere.[1]

No improvement in performance was evident with the practice gained during the course of the experiment. The inter-subject variability in the performance of this task was relatively large at the two lower luminances as compared to that for the two higher luminances. This presumably could be accounted for by the fact that three of the subjects complained that they were unable to maintain parafoveal fixation for the lowest luminance condition. In summary, the human visual system was found to be able, under certain conditions, to detect the

movement (75 per cent threshold) in depth of an object in an otherwise stimulus-free field when the object traversed approximately 2 per cent of the original distance. This is equivalent to a change in visual angle of 2 per cent, and since the stimulus had an original subtense of 40 min of arc, a change of less than one min of arc was perceived. Under the conditions of higher luminances and binocular viewing movement was correctly reported more than 90 per cent of the time when 5 per cent of the distance was traveled.

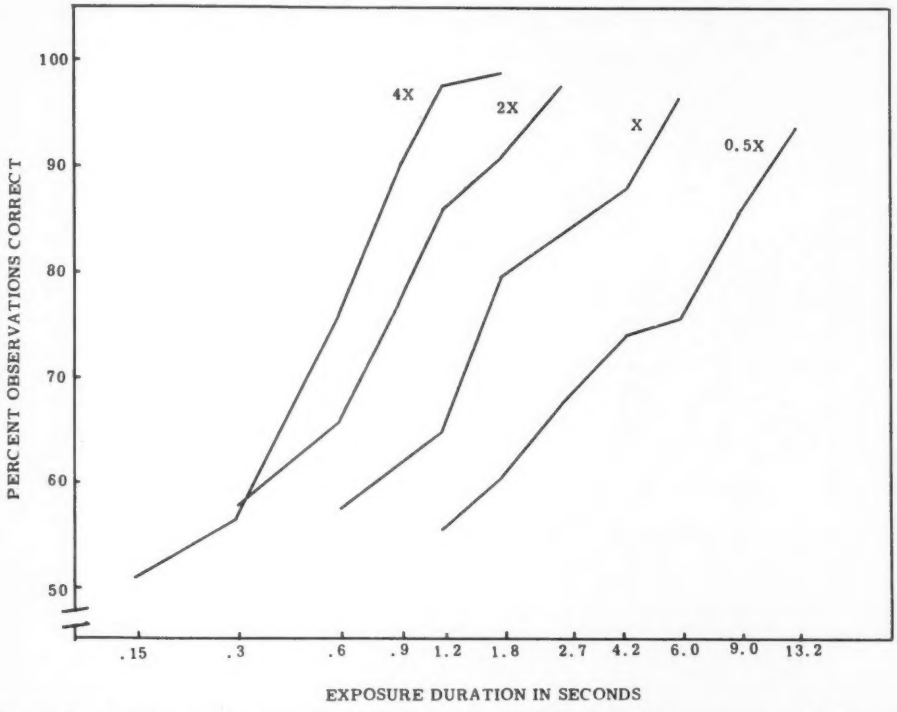

Fig. 3. Accuracy of perceiving movement in depth as a function of duration of observation for each of 4 target speeds. The value of *X* is 3.3 in./sec. The *X* speed was used in the first study. Each point is based on 240 observations, 60 by each of 4 subjects.

STUDY NUMBER TWO

The second study was conducted to investigate the effect of target velocity on the ability of subjects to perceive movement in depth.

Apparatus and procedure. The conditions were identical with those of the first experiment except that the luminance level of the moving stimulus was maintained at 1.0 ft-Lambert and the speeds used were 1.65, 3.3, 6.6 and 13.2 in./sec. Also the durations of observation, although still at fixed values, extended down to 0.15 sec. The slowest speed used resulted in 0.6 per cent visual angle change per sec, the fastest in 4.8 per cent change per sec. The 3.5 in. stimulus disk at the 25 ft point of onset, subtended 40 min of arc. The absolute change in visual angle at the onset of the stimulus is about $\frac{1}{4}$ min of arc per sec at the slowest speed and 2 min of arc per sec at the fastest. At the slowest rate of change in stimulus subtense the subjects were unable to see movement (or ap-

parent size change) directly, but by continued observation were able to report whether the stimulus object appeared larger (closer) or smaller (more distant) than it appeared at onset. At the faster rates of change, the subjects were able to perceive a definite movement (or change in apparent size). An analogous situation is found in observing the movement of a clock's hands. The movement of the second hand may be seen in a short observation time, whereas the minute or hour hands must be observed for a longer period. Even then no movement is observed, but the fact that movement has occurred is evident from a change in position over a period of time.

Results

Fig. 3 shows per cent of observations correct as a function of the exposure duration for each of the four target speeds used in the study. The data shown are for the binocular and monocular conditions averaged. For all conditions, the binocular thresholds were slightly lower than the monocular thresholds. It is evident from the figure that longer observation times are required to maintain a given level of performance as the target speed is reduced. As in the first study, a small response bias occurred. The subjects reported the object to be approaching in 50.7 per cent of the trials, when in actuality it approached in 50.0 per cent of the trials.

Fig. 4 is a plot of the 75 per cent thresholds (75 per cent of observations correct) for both monocular and binocular conditions as a function of target speed. The superiority of the binocular conditions was evident for all target speeds and this superiority was evident in the data for each of the four subjects. It should be noted that for the slowest speed (1.65 in./sec) the subjects required 6 sec of observation time to acquire 75 per cent threshold level of performance, for monocular viewing. At the fastest speed (13.2 in./sec) they required only 0.65 sec. Thus, when the target speed was increased by a factor of 8, the time required for threshold performance was reduced by a factor of 9. This indicates that the total distance traveled to acquire a threshold level was not greatly affected by the extreme target speeds used in the study.

The relation of target speed and the distance traveled to threshold is more clearly evident in Fig. 5. This graph shows per cent distance traveled to threshold as a function of target speed for various threshold values. It is interesting to note that the required per cent

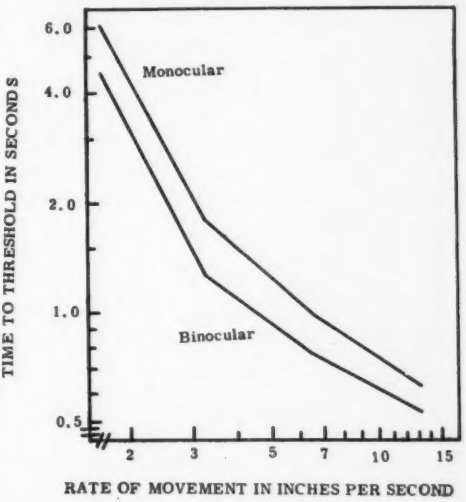

Fig. 4. Observation time required to achieve 75 per cent correct responses as a function of target speed for monocular and binocular viewing conditions.

distance traveled to achieve 95 per cent correct responses decreased with greater stimulus speeds. However, as the criterion level is reduced, the slower stimulus speeds result in optimum performance. This indicates that the slopes of the probability-of-detection curves (Fig. 3) are steeper for the greater speeds. A possible explanation for this effect is that for the greater speeds the observation times are extremely short, and since a rigorous eye fixation prior to stimulus onset was not used in the experiment, the time required to fixate the stimulus at onset disproportionately

penalized those conditions with the greater stimulus speeds, particularly for the lower threshold criteria. Considering all criterion levels, the 6.6 in./sec speed yielded lower thresholds for perception of movement.

Fig. 6 is a plot of the observation time required to reach threshold as a function of target speed for each of the four subjects in the experiment. It is evident that the variability between subjects is much less than the variability contributed by the experimental condition of target speed.

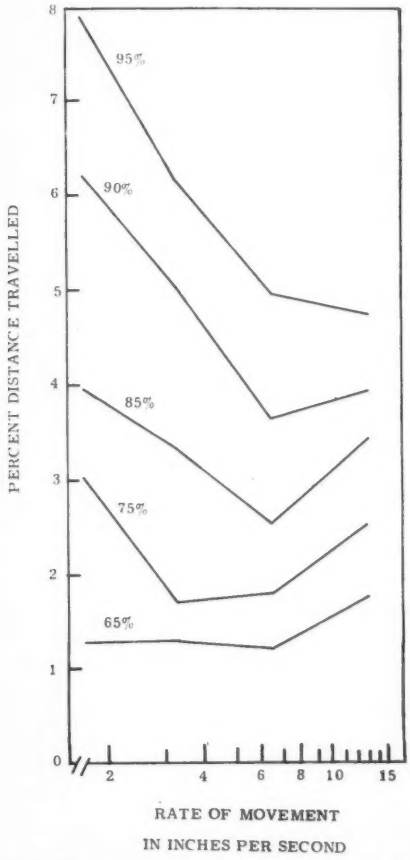

Fig. 5. The per cent distance traveled to achieve various threshold levels of performance as a function of target speed. The per cent values on each curve indicate the per cent of observation correct.

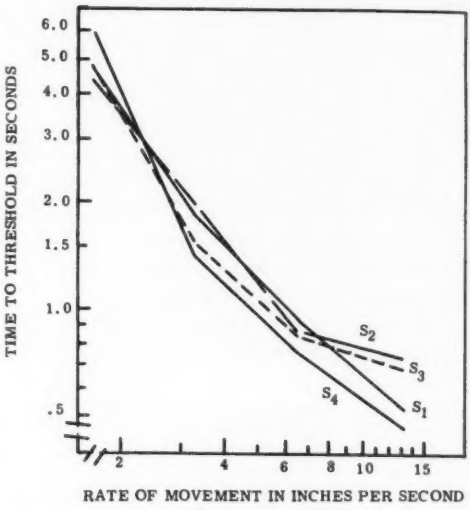

Fig. 6. Observation time required to achieve 75 per cent correct responses as a function of target speed for each of the four subjects used in the experiment.

DISCUSSION AND SUMMARY

In both of the studies reported, the visual angle subtended by the target at onset was 40 min. In making the discrimination of whether the object approached or receded, the subjects' cue was the perception of the direction of a change in angular subtense of the object. The subjects, in most cases, reported that a movement was perceived and not a change in object size. It was observed, that under certain conditions the subjects achieved the 75 per cent threshold criterion when the visual angle of the target changed by 2 per cent. This is about equivalent to a 2 per cent change in distance for the angular subtenses involved or an absolute increment, or decrement, in visual angle of about 0.8 min of arc. If one attempts to extrapolate these data to target objects which subtend, originally, visual angles different from those used in the present study, the extrapolated values would vary significantly depending on whether a per cent visual angle change (a Weber ratio) or an absolute visual angle change were to be

used. Subsequent empirical investigation will probably indicate that perceived movement in depth as a function of original angular subtense of the target object will fall somewhere between the Weber prediction (per cent visual angle change) and the prediction based on a constant increment change of 0.8 min.

The interaction of the threshold criterion level and rate of target movement (see Fig. 5) may be an artifact of the experimental procedure. Since no fixation light was involved, the initial position of the eyes during onset of the stimulus was frequently such that the retinal image was peripheral to the fovea. The subjects also reported that at stimulus onset they were frequently "out of focus". The time lost in accommodating and fixating the stimulus would be independent of object velocity. Thus, the faster speeds were disproportionaly affected by this aspect. The fixation light was not used intentionally so that the visual task would more closely simulate an operational situation.

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Aircraft Ground Emergency Exit Design Considerations

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A review of the literature shows that emergency ground conditions for aircraft occur with sufficient frequency to require emergency escape devices. The nature of these emergencies allows for a reasonable possibility of escape if care is taken in selection and design of escape provisions. For normal low-wing aircraft, the inflatable escape slide provides for reliable support during descent. Extensive experimental data are given for design of overwing emergency exits and similar installations. These data show some significant relations to body dimensions and agility of the subject. Standard methods are necessary for comparing escape exit tests in the future, if optimum design of exits and devices for minimum weight and space requirements is to be achieved.

INTRODUCTION

Among the important safety considerations in vehicle design is the problem of providing a variety of paths for leaving the vehicle in case of fire, collision, or malfunction. The solution of this problem for vehicles of large passenger capacity usually takes the form of additional doorways or hatches and auxiliary escape devices which may be used if the normal exit is blocked or is inadequate for the required volume of traffic.

Human factors problems arising in the design of such exits and devices for escape from aircraft on the ground have been noted in the literature. The Douglas Aircraft Company undertook a systematic study of population variables and speed of exit for a large number of exit configurations. This was done to provide a more systematic and realistic approach to design than the existing literature permitted. A summary of the results of these experiments and a description of some of the study methods used are presented herein. The results are of interest to designers of many types of vehicles and stationary installations. For example, the problems of rapid evacuation may arise in designing doors in bulkheads of naval ships and submarines, in buses, in missile ground support trailers, in trains, and eventually in space ships. Non-vehicular uses might be rocket test installations, chemical plants, or other locations where fire or corrosive gas escape in close quarters requires rapid evacuation.

BACKGROUND

A systematic study of emergency escape design requirements shows a need for data on frequency of need, available time for exit, and population description of the users, as well as the actual physical design limitations to compare with existing regulations. The following discussion will consider each of these aspects in the order named.

Frequency of Need

The first concern is to find if emergency exits are really needed at all. Statistical data on frequency of use and an evaluation of the relative effectiveness of similar devices are helpful for this evaluation.

A comprehensive study of the statistics of emergency exit use in actual aircraft accidents was published by the CAB[16] in 1952. Table I gives the frequency of fires and different gear positions for 122 accidents to tricycle gear transport aircraft in the years 1948 through 1951. These data indicate a high probability of difficult descent conditions combined with risk of fire which justifies installation of emergency exits and associated descent devices for rapid egress.

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TABLE I

Gear Position and Frequency of Fire in Accidents Involving Transport Type Aircraft[16]

Position of gear	*Totals*	*Per cent*	*No. of fires*	*Per cent*
Wheels down	68	55.7	19	28.0
Wheels up	26	21.3	13	50.0
Partial failure	28	23.0	4	15.2
Total	122	100.0	36	

Another analysis involving 43 accidents indicates the frequency of need and actual use of various emergency exits and descent devices, as shown in Table II. Table III gives a breakdown of usage by types of doors and various emergency descent devices associated with them.

TABLE II

The Need for and Use of Descent Devices for Passenger Evacuation Following 43 Accidents to Tricycle-Gear Transport Aircraft[16]

Attitude of aircraft	*Not needed*	*Descent devices*		*Totals*
		Needed	*Used*	
Wheels down	1	9	(7)	10
Nose down	12	3	(0)	15
Wheels up	12	2	(0)	14
Nose high	2	...	...	2
Left gear failure	1	...	...	1
Overturned	1	...	...	1
Total	29	14	7	43

These data indicate a usage for the several types of doors and emergency exist and descent devices on aircraft and point out those which are most often used. The study further disclosed that different areas were blocked by fire or obstructions resulting from the circumstances of the accident. Therefore, exits should be distributed at different places along the fuselage where practicable. It is also clear that there were many cases where a descent device was needed and was not available because of malfunction, lack of crew training or excitement. This points to the need for simply operated, reliable equipment to provide an effective means of escape.

TABLE III

Use of Various Exits and Descent Devices in 43 Aircraft Accidents[16]

Main door	
With rope	3
With Jacob's ladder	2
With slide	2
Jump or step down	17
With outside aids	3
Ambulance or truck (2) ladder (1)	
Total	27
Service or other door	
With rope	3
With slide	1
Holes in fuselage	7
Jump or step down	11
Ladder	1
Total	23
Overwing emergency exit	7
Other emergency exit—window	7
Pilots window or escape hatch with rope	9

Available Time

The urgency of escape is another important consideration and is affected by many factors such as fire, malfunction of equipment, temperature protection, toxic gas generation, smoke, danger of explosion and so on.

A study of fire progression during crash has provided a beginning for objective determination of necessary escape time. Pesman[21] studied skin injury and respiratory system damage as limiting criteria for escape. Other forms of heat injury such as heat prostration take longer to develop or require a heat source with a temperature higher than that necessary for skin injury. Skin injury to the level of "unbearable pain" (42° to 45°C) "may be strong enough to delay one from taking preventive measures to escape fire".[3] Pesman calculated the heat absorbed by the skin of a

subject from the temperature history of a copper-bulb calorimeter in a series of experimental airplane crashes (see the single line connecting data points in Fig. 1). These data were compared to Buettner's data[3] after they had been recalculated in terms of heat absorbed by the skin versus time at which unbearable pain occurs (shaded area between curved lines). The point where the solid line crosses the shaded area gives the time at which the pain becomes unbearable and incapacitation may presumably prevent escape.

ture respiratory damage limit as criteria. The times ranged from 53 to 296 sec, depending on conditions.

The escape time as limited by carbon monoxide concentration exceeded 300 sec, and that for carbon dioxide was generally greater than 10 min, and in no case was it the limiting factor.

Insufficient physiological data were available to determine if smoke and aldehydes were limiting conditions to escape time.

The discussion of life rafts, life vests, other

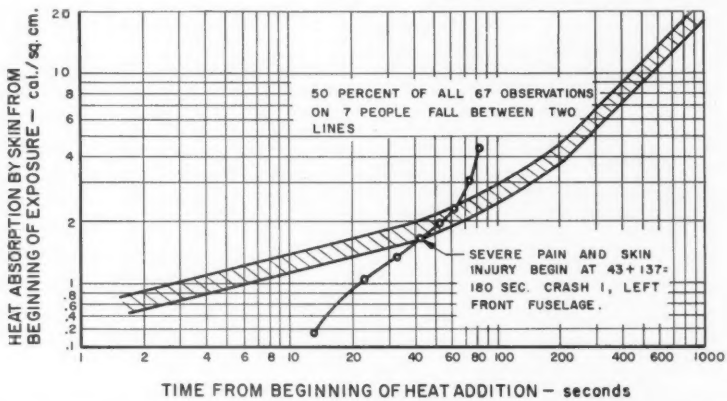


Fig. 1. Time until unbearable pain occurs if dorsal side of forearm is exposed to infrared radiation and absorbs indicated amount of heat.

Another criterion of skin injury considered by Pesman was that of second degree burn. Although this is considered survivable by medical authorities, it may be incapacitating, according to Pesman.

The respiratory system criteria chosen by Pesman included air temperature and toxicity tolerance. An air temperature of 590°F was the temperature criterion chosen since it was a value known to have been withstood by one person for a short time, though it may not be the ultimate limit.

Pesman's observations indicate that the tolerance times were similar in aircraft crash fires whether one used time to reach skin burning, second degree burns or the high air tempera-

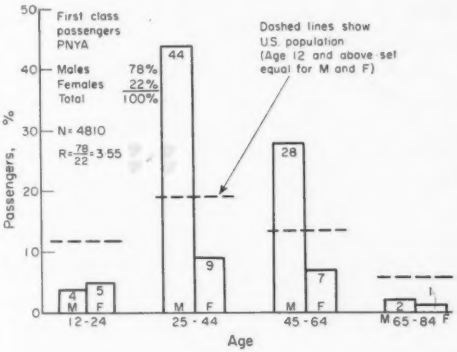
flotation gear, aircraft altitude and other factors related to time for escape from floating aircraft is not considered in this discussion.

Population

Given that emergency exits are required and knowing the time available for the use of the exits, the next need is to specify the using population in terms of its pertinent attributes. Selection of attributes which are indeed pertinent to escape time requires considerable study. Two broad classifications are suggested: agility and size.

The importance of basic agility differences can be readily visualized in the reader's mind by thinking of opposite extremes, such as

trained young paratroopers and elderly women. This suggests two likely criteria related to agility: age and sex. Sex differences may be further affected by styles of women's clothing which may hamper movements. Survival equipment such as life vests and parachutes may also restrict movements of all passengers. Information on age and sex distribution of the air-traveling public has been collected by various agencies such as the Port of New York Authority,[1] airlines operators,[20] Society of Weight Engineers[18] and the Department of Commerce. Figs. 2 and 3 summarize two of such studies. These studies were made prior to the advent of present large-scale jet transport



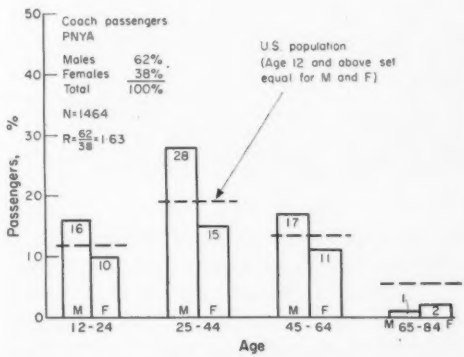
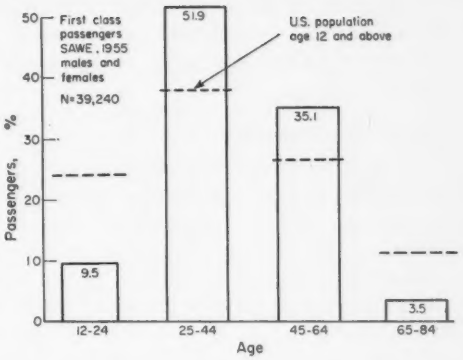


Fig. 2. Age distribution of male and female passengers for first-class and tourist air travel passing through New York City. Note comparison with U.S. population age 12 and above.



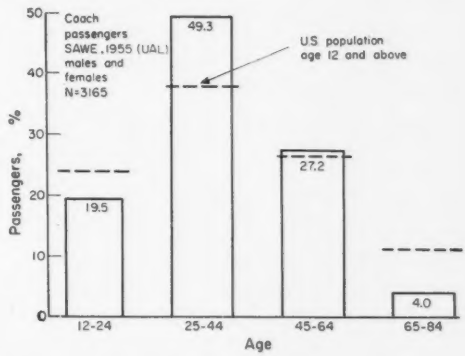


Fig. 3. Age distribution of first-class and tourist air passengers compared to the age distribution of the U.S. population.[18]

operations. A significant trend can be seen in the fact that the coach population more nearly approximates the U.S. Census than the first-class population. Such data will be of obvious value if agility can be correlated with age and sex to produce significant indices.

The factor of size is also clearly visualized by considering the extreme situation of very small openings and very large persons. Less clear are the effects of extended step distance, corner radii interferences and overhead obstructions. When such effects are numerically described, they can be related to general population measurements reported by Hertzberg,[9] Hooton,[10] and Roebuck.[24]

Correlation of time of escape with the above suggested factors was one purpose of the overwing exit studies reported later in this paper.

Design Limitations

The designer of an aircraft fuselage is faced with a host of other requirements governing his selection of exit configurations. An improvement in any one dimension must be weighed in consideration with weight, passenger seating requirements, pressure strength, styling, aerodynamics and so forth. These considerations affect such important dimensions as corner radius, distance from floor to sill and sill to wing, height and width of the exit. Additional considerations involve the space requirements, reliability and manufacturing problems of automatic devices as compared to slower, simpler devices for aiding descent.

The following is a review of findings from previous investigations of aircraft emergency ground escape provisions.

TIME STUDIES: AIRCRAFT EMERGENCY EXIT AND DESCENT DEVICES

Although the effects of exit size and the requirements that determine the type of associated descent device are closely related, they can generally be considered separately in commercial aircraft. Auxiliary descent devices will be considered first in this discussion.

Descent Devices

Among the several devices which may be used for descent are ropes, poles, braked slings, ladders, and slides. Table IV gives values of time for several of these devices.

Investigations by King[15] have aptly demonstrated that ropes are not satisfactory for many persons among the general traveling public, as a primary means of descent from aircraft. Older, obese persons require so much additional assistance that the rope is largely a psychological aid. However, for persons in a relatively good state of health, they are among

TABLE IV

Comparison of Average Emergency Escape Times for Various Descent Devices[15]

Descent device	*Average time (sec)*	*Number of civilian subjects*	*Average time (sec)*	*Number military subjects*
Slide	5.18	31	1.75	14
Ladder	10.61	31	3.45	14
Rope	9.36	22	1.69	14
Jacob's ladder	11.52	25	5.38	14

the fastest devices. The rope should be between $\frac{3}{4}$ in. and $1\frac{3}{4}$ in. in diameter, which gives a gripping circumference of 2.36 to 5.25 in. The engineering problem of providing storage for a rope in transport aircraft is not as simple as may be thought, since space is limited. A common method is to store the rope in a tube running up and around the perimeter of the fuselage in aircraft with large fuselage diameters. This prevents the possibility of kinking or knotting, but it pre-empts valuable space required for air ducts, wiring, soundproofing and cables necessary for the operation of the craft. A recent innovation in this field is the use of nylon tape of the order of $\frac{1}{4}$ in. by 1 in. in a cross-section. The perimeter is approximately $2\frac{1}{2}$ in. Coating the tape with a latex rubber material gives a satisfactory gripping surface. Use of this tape reduces the weight of escape line by 63.7 per cent and the storage space by about 37.7 per cent of that required for a hemp rope of $\frac{3}{4}$ in. diameter. Informal tests not reported here have demonstrated that a man can descend a reasonable distance with such a tape without burning the hands. Such tapes are currently installed on the DC–8 jet transport.

An additional means for providing greater safety would be a rope ladder (Jacob's ladder). This device has problems associated with its use such as the tendency for the subject's feet to swing away from under him. If attendants on the ground support the ladder, this problem can be reduced. However, use of the ladder is not advisable for untrained persons. A recent variation of a Jacob's ladder is a ladder

TABLE V

Exit Rates for Slides at Doors: Summary of Test Results[16]

		Average rate: sec/passenger		
Slide type	*Door type*	*Jump method*	*Bar-hold and jump method*	*Sit-scoot method*
Mica-Neoprene coated	Main	1.23–1.66		
Neoprene-coated	Main	1.81–2.88		
Vinyl-coated	Main	2.15		
Neoprene-coated	Crew	2.3		
Canvas	Main		2.33	
Canvas	Main			2.54–3.61
Canvas	Crew			3.75

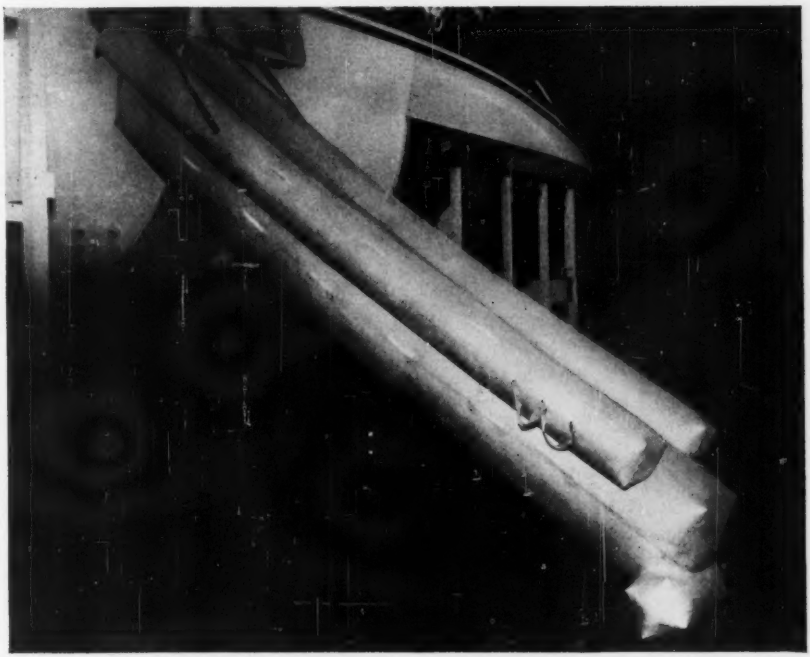


Fig. 4. Inflatable slide manufactured by Air Cruiser Co. Inc., New Jersey.

constructed of aluminum alloy tube rungs and nylon tape sides.

Another associated escape device is a sling or loop attached to the end of a rope. The rope is then passed through a braking device. In this method the rope moves with the man. The braking device may be manually or automatically controlled, the latter being preferred.

The braked-pulley rope-sling descent device was designed originally for use in escape from buildings on fire. In connection with engineering development studies of a large military transport aircraft a device of this nature was

tested.[8] The results indicated that an average descent velocity of 1.6 to 4.0 ft/sec was achieved. This was judged too slow for rapid evacuation of a military crew. Further studies indicated that a descent velocity of 8 to 10 ft/sec would be desirable and within safe landing forces for the man. Modifications of the Davy braked pulley increased the descent velocity to a range of 4 to 5 ft/sec maximum.[8, 11]

Slides

Escape slides have been in use for a long time in many applications, but it is still very difficult to find actual measured data on time of descent as a function of angle, distance, material, clothing, etc.

Table V shows data compiled from tests of hand-held cloth slides on various aircraft.

Two important problems face the user of hand-held slides. The first is that the slides must be unpacked, hung out the door and then prepared for use by having two persons climb down to the ground and hold them. The second is that these two persons may be motivated by instincts of self-preservation to leave the scene of a fire and impending explosion, thus rendering the slide useless. These problems have been overcome to a large extent by development of inflatable slides (Figs. 4 and 5). These are relatively easy to

Fig. 5. The Elliott inflatable slide manufactured by the Survival Equipment Corp., England.

Another device of utility in some applications is a rigid ladder. Woodson[26] recommends ladders be used for angles of 50° to 90° from the horizontal using flat treads from 50° to 75° and rungs thereafter. The inherent danger of the ladder is the search time and uncertainty in locating the rungs. In general, King[15] found ladders less desirable than ropes or slides, except where speed was not important.

Stairs are satisfactory for inclines of 20° to 50°, according to Woodson.[26]

actuate and provide firm support without assistance.

In designing for slide installations the position of the aircraft with wheels up and with various wheels collapsed should be considered. Informal tests on relatively rigid slides indicate that the optimum angle considering speed of exit and possible injury due to striking the ground is about 38°. However, this may range from 28° to 45° due to possible attitudes of the disabled aircraft. Reduced inflation pressures and more flexible design allows a partial buckling action permitting shallow exit angles on slides with nominally steep slopes in the unoccupied condition.

As regards time of escape, the inflatable slide provides a more consistent time of preparation than the hand-held type. This is usually less than 30 sec. Various treatments of the surface may have to be developed to solve such problems as extreme exit velocity at high angles of descent, reduction of static electricity and heat damage due to fire. The slide shown in Fig. 4 has an aluminized covering for heat resistance and a short nylon runner strip in the center to provide a quick start after sitting down. Slides still present a problem in high winds due to difficulties of restraint.

Exit Configurations

Most exit designs in the past have been based on considerations of overall body dimensions and brief informal tests. For example, most aircraft emergency exits were in the range of 19–24 in. wide which is a reasonable approximation to average shoulder width of the Hooton[10] sample (18.3 in.). In height of opening they have ranged from 72 in. for a walk-through type door to about 17 in. high. These figures are most likely derived from informal studies. For several years the FAA required that a 19 × 26 in. ellipse must pass through the exit. These designs were later tested in more formal, timed studies using as subjects persons approximating the expected population as reported by King.[12, 14-16] For example King[15] recorded time by the use of motion-picture records which included a clock in the field of view. The population included a reasonable range of ages and both men and women. Procedures of exit by means of overwing exits and main doors using slides

TABLE VI

Exit Rates for Overwing Window Exits: Summary of Test Results

Exit size (in.) Width	Height	*Step distance (In.)* Up	Down	*Average rates (sec/passenger)*	*Test arrangement*	*Reference*
24	36	23–29	25–36	1.60–2.70	Mock-up	16
24	31	23–29	25–36	1.90–2.80	Mock-up	16
21	31	24	25	2.0	Boeing 377	6
21	24	24	25	2.25–3.1	C–54	16
21	24	24	25	2.9–3.9	DC–4	16
26	19	28	32	2.25–3.4	Constellation	7
19	26	23–29	30–36	2.50–3.0	Mock-up	16
19	26	25	30	4.8–6.2*	Convair 240	5
19	26	25	36	5.5–6.5*	Convair 240	5
17	26	23–29	25–36	2.9–4.2	Mock-up	16

* These high values are probably due to the method of investigation which was more concerned with procedure than absolute rates.

For comparison, the average values obtained for relatively unobstructed door openings (wheels up, ramp at main doors) are of the order of 0.8 to 1.5 sec/passenger.

TABLE VII

Exit Rates from Aircraft Expressed in Terms of Goodness Factors[12]

Type and location of exits	*Usefulness*	*Probable availability*	*Average relative escape (D/W) rate*			
			Landing gear up		*Landing gear down*	
			Mode	*Range*	*Mode*	*Range*
Doors—Fwd. of Wing	All	Fair	1.0	(Std.)	1.0	(Std.)
Windows—Fwd. of Wing	Some	Fair	0.2	0.1–0.3	0.4	0.2–0.4
Windows—Over Wing	Most	Fair	0.4	0.3–0.5	0.7	0.5–0.7
Windows—Aft of Wing	Some	Good	0.2	0.1–0.3	0.4	0.2–0.4
Doors—Aft of Wing	All	Good	1.0	(Std.)	1.0	(Std.)

SUMMARY:

Best—Doors aft of wing.

Worst—Windows forward of wing.

Notes:

1. "All" means all ambulatory passengers may use exit.
   "Most" means all except very obese passengers or those with markedly impaired agility may use exit.
   "Some" means only young, agile passengers may be expected to use the exit.
2. Exits forward of wing are likely to be less available due to crash damage and ditching attitude.
3. Factor $D/W = \frac{\text{escape time through door}}{\text{escape time through window exit}}$ indicates that window exit is only D/W (values generally less than 1.9) times as good as a door (having a value of 1.0).

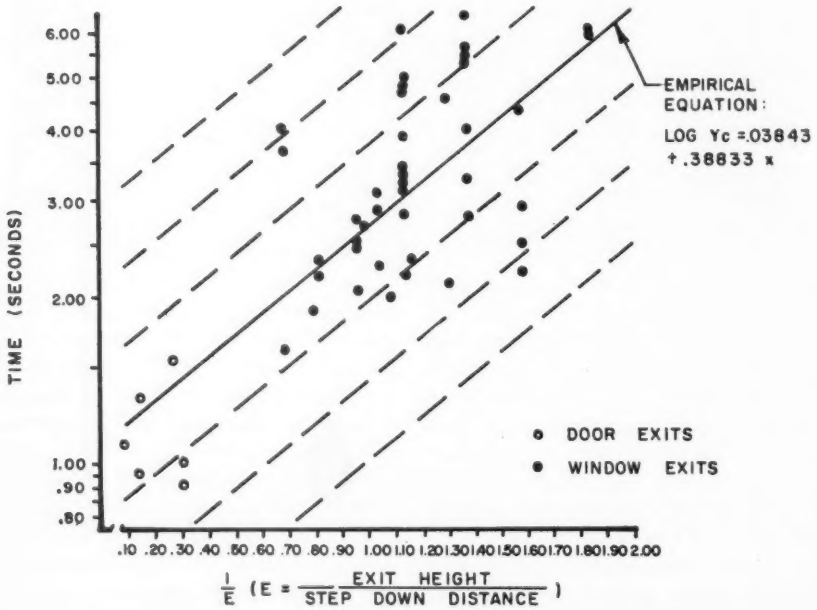


Fig. 6. Exit time as a function of an empirically defined "ease factor".

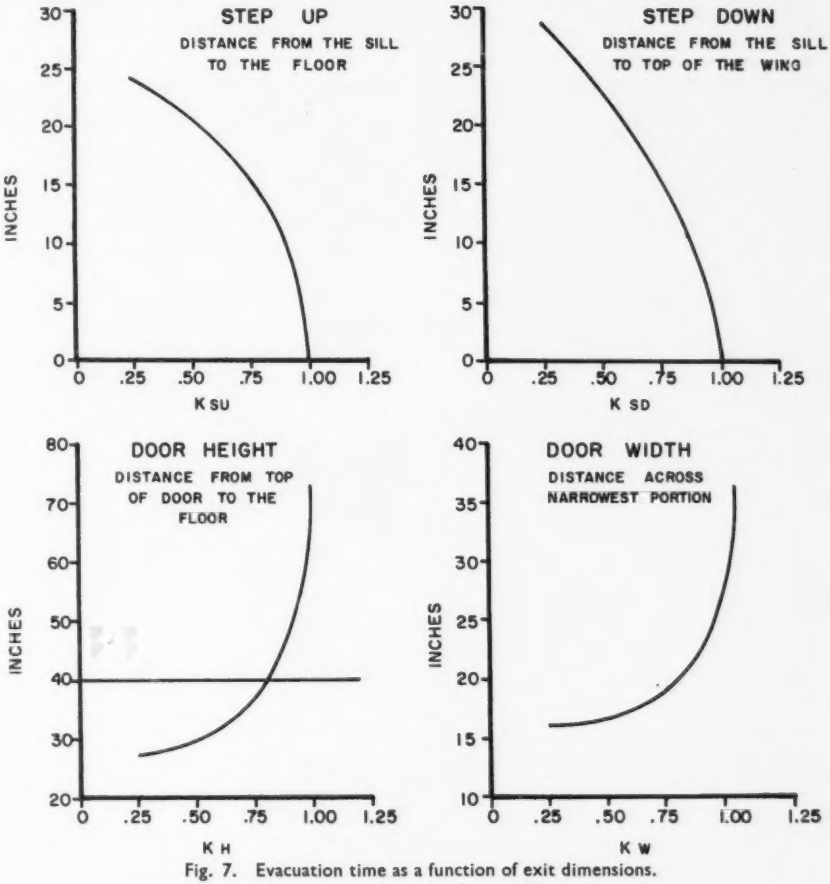


Fig. 7. Evacuation time as a function of exit dimensions.

Evacuation Means	Ke	Door Egress Rating= $50 \times Ksu \times Kso \times Kh \times Kw \times Kf$
Steps		
Inflatable slide	1.50	Maximum Passenger Capacity of
Non-inflatable slide	1.0	Aircraft=sum of egress
Ladder	0.25	rating of doors on one
Rope	0.10	side of fuselage

were studied. The information obtained by King is useful in defining the value of any given exit but it gives only a single point on a curve of exit time vs. size of exit. Results of several studies by the CAA, CAB and some airline manufacturers (King,[12–16, 22, 25] CAA–CAB[4–7]) are summarized in Table VI. Such data are valuable but obviously leave many areas unknown.

The combined results of several such tests were summarized by King.[14] Table VII presents his compilation in terms of a "goodness factor". King also included Roebuck's empirical formula which defined an "ease factor" $\left(E = \dfrac{\text{door height}}{\text{step-down distance}}\right)$ which was related to time (T) of exit by the relation $E = 0.333 + 1.467/(T - \frac{1}{4})$ (see page 45 of King[14]). King added some unpublished data and plotted $1/E$ vs. time (Fig. 6). Such data

are still too coarse to be useful in detail design. It was recognized that what was needed was a set of curves giving effects of changes in exit dimension on exit time. Also a way of evaluating multiple dimension changes would be desirable. An example of the kind of information presentation desired was proposed by the Boeing Airplane Company's Safety Research Group (Fig. 7). In the light of the need for more exact information the Human Factors Group of the Transport Division of the Douglas Aircraft Company initiated an experimental study to discover the effect of varying exit dimensions on exit time.

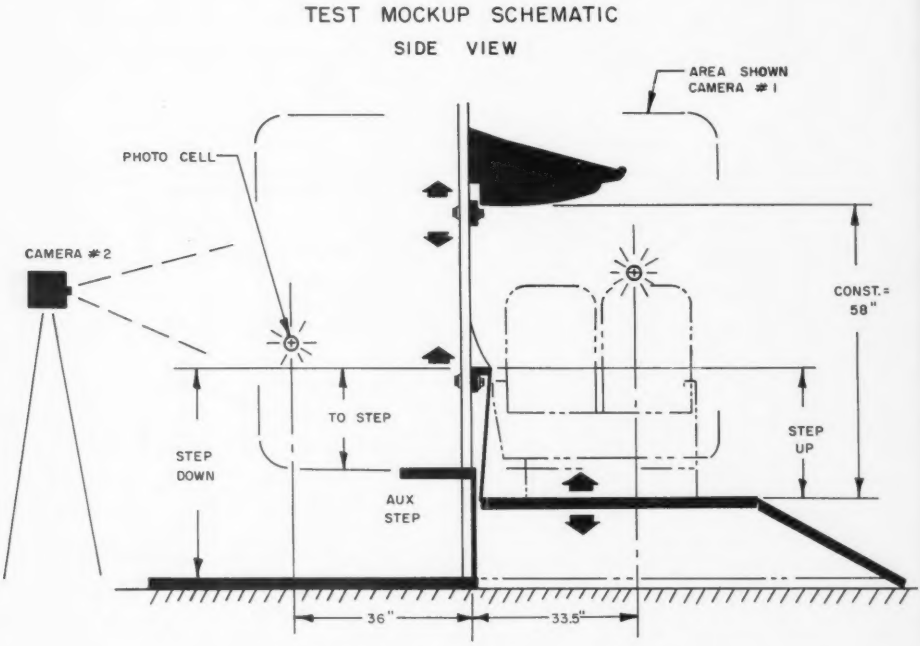


Fig. 8. Schematic view of the test mock-up.

THE DOUGLAS AIRCRAFT COMPANY OVERWING EMERGENCY EXIT STUDY

The purpose of these tests was twofold. The first was the development of a general approach to answer basic questions concerning aircraft overwing emergency exits. This was part of a continuing program of population studies for airframe design. The second was the evaluation of proposed emergency exit configurations for the DC-8 jet transport. The first purpose is of most concern for this paper because of the wider applicability of the results. However, some of the experiments performed to comply with the second purpose were of considerable interest since they involved essentially naïve subjects covering a wide range of ages. The dependent variable measuring performance was in all cases the time of exit per person as averaged over the best three out of five trials. The independent variables of interest were dimensions of opening height and width, step-up and step-down distances, corner radius and passenger seat and berth interference conditions.

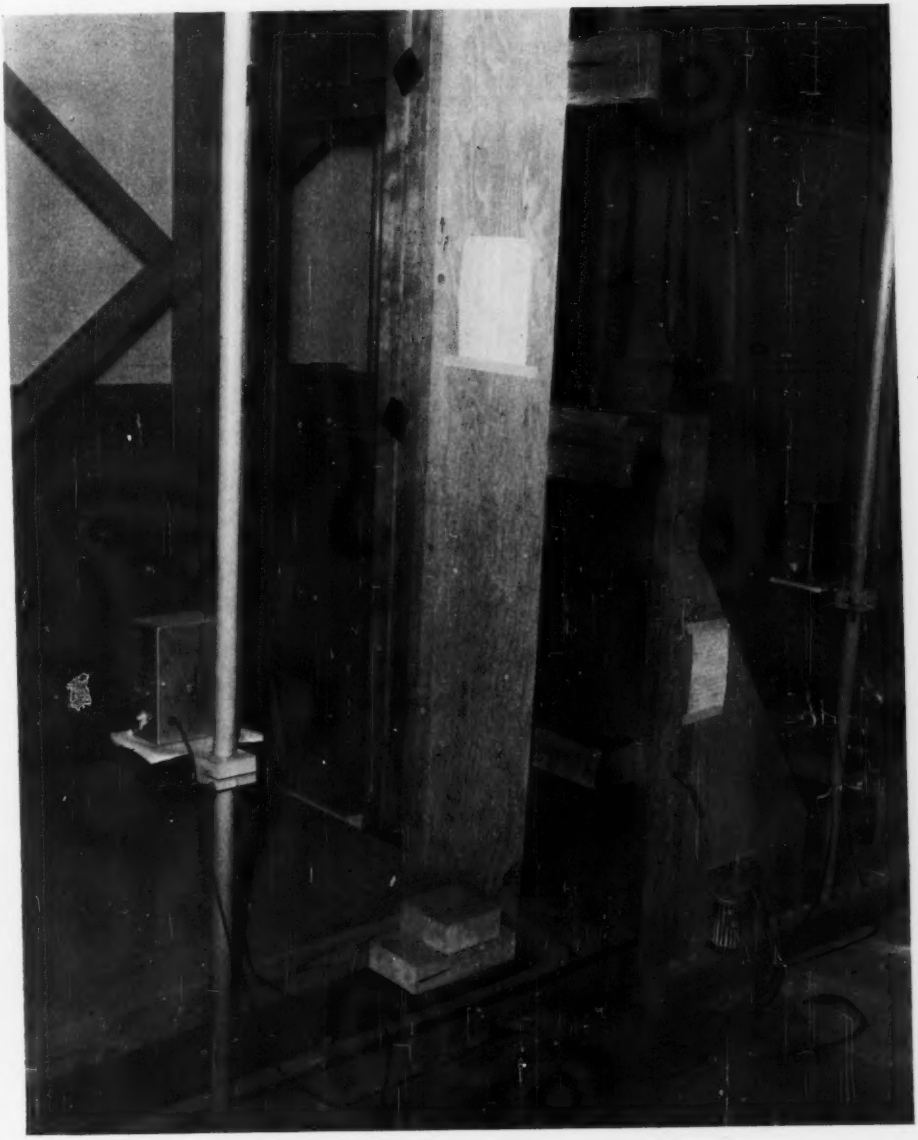


Fig. 9. Apparatus for measuring exit time showing general type of construction.

Fig. 10. Apparatus for measuring exit times. Front view of opening.

Apparatus

To study large changes of many variables, it was necessary to design a flexible mock-up of the overwing exit. The apparatus, which is shown in Figs. 8, 9 and 10, allowed for variation of more than 7 ft in opening height, floor to wing difference and step distances up to 4 ft, and width up to 3 ft. Provisions for installation of seats, baggage racks, corner radii, berths and auxiliary step platforms were also included (Fig. 11).

Time was measured by means of two photocells located as shown in Fig. 8. These photocells were connected to a Sanborn two-channel tape recorder. Breaking the light beam to the photocell caused a displacement of the stylus on the tape of the recorder. Calibration of the time scale was made to an accuracy of 0.01 sec. The clock shown in Figs. 11 and 13 was not used for timing purposes.

Procedures

Volunteer subjects were apprised of the nature of the tests. Twenty-three different body measurements were taken on a group of 270 of these persons from the Engineering and Tooling Departments of the Douglas Aircraft Company. The description of the measurements is given in Fig. 12. These were selected for two purposes. Some are standard dimensions for comparing the study population to the expected passenger population. Others such as Standing Measurements, Numbers 2, 7, 8 and 9, and Sitting Measurements, Numbers 12 and 13, are experimental measures of static body movement limitations proposed as a means of defining agility. These standard measurements were to be compared by correlating results of time trials on various exit configurations.

Because of the large number of tests desired,

Fig. 11. Modification of apparatus to permit study of effect of corner radii and seat location on exit time.

it was uneconomical to obtain a representative naïve group of subjects for each test. It was therefore decided to utilize one group of subjects for a complete homogenous series of tests labelled a Session. In each session only a small number of variables was studied, all other variables being held constant. Early in the pilot studies it was apparent that learning would have important effects on performance. Instead of absolute values for inexperienced subjects, relative minimum values for experienced subjects were obtained. The test

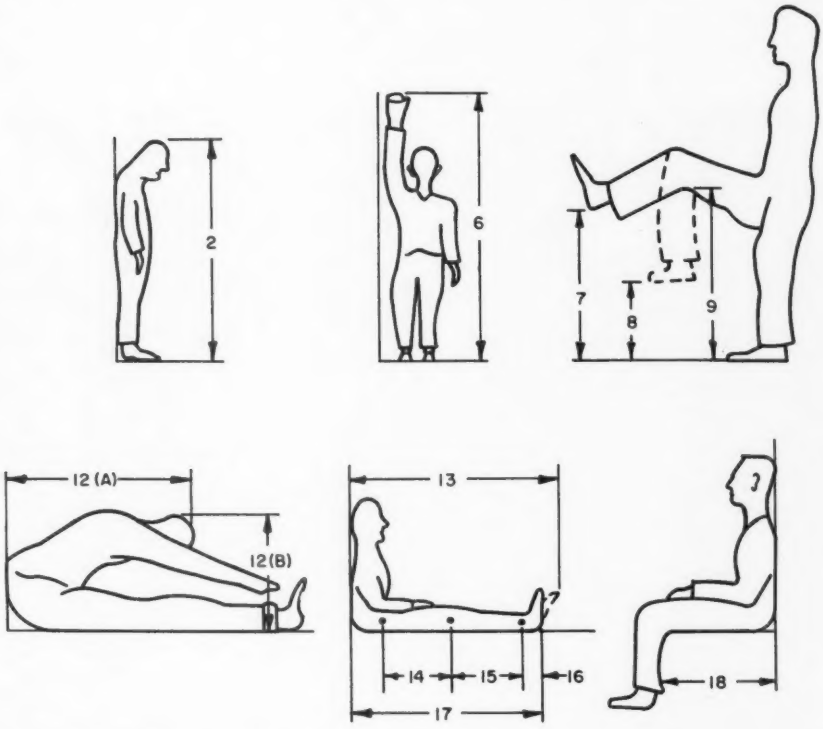


Fig. 12. Description of anthropometric measurements made on test subjects used in emergency exit studies.

Standing Measurements

1. Stature:
   (A) Shoes
   (B) No shoes
2. Stature: head bent full forward (no shoes)
3. Shoulder height (acromion)
4. Wrist height (base of palm)
5. (3)—4=arm length
6. Overhead reach (useful, feet flat)
7. Lowest point on heel (thigh raised, lower leg extended, toe up)
8. Lowest point on heel (thigh raised, lower leg vertical, foot flat)
9. Popliteal surface (left thigh raised)

Sitting Measurements

10. Shoulder width
11. Greatest body depth:
    (A) Chest
    (B) Abdomen
12. Bent forward:
    (A) Width
    (B) Highest point
13. Leg length (foot extended)
14. Tibiale to trochanter
15. Malleolus to tibiale
16. Lateral malleolus height
17. Leg length (left)
18. Seat length (buttock—leg width)
19. Buttock to knee
20. Knee height
21. Popliteal height

schedules selected called for 5 runs of each test. The lowest 3 of the 5 individual times were averaged for each individual, then these average individual times were averaged for the group. Test configurations were generally arranged in order of expected increasing difficulty. Thus, if the average time increased, it could be expected that the effect was due to the exit, not due to additional learning which would tend to lower average times. Individual times were achieved by asking subjects to wait until they had a clear path ahead of them before passing the first photo cell.

After considerable experimentation with the above method, tests were run with inexperienced subjects passing through Civil Aeronautics Regulation type exits and proposed DC–8 exits. These tests were recorded by motion pictures on standard speed film with two cameras, one taking a view perpendicular to direction of movement and another aimed directly into the exit (Fig. 13). No instructions as to technique were given the subjects, and no attempt was made to keep the subjects separate. Although there were distractions due to the photographic equipment, the spacing conditions closely represented those expected in an actual emergency.

Fig. 13. Exit time experiment in progress.

All told, 395 different test configurations and some 12,000 individual transits were made in the combined general and specific studies.

SUMMARY OF BASIC STUDY RESULTS

Height of Opening

Generally speaking, the larger the opening, the faster one can get through it. However,

after the height of the lintel above the floor becomes greater than body stature, little further change in time is expected. This is confirmed by experiments which had lintel heights up to 8 ft 4 in. For example, in a series where equal step-up and step-down distance were maintained, Fig. 14 shows the time of passage plotted as a function of sill to lintel distance (H) for several fixed step distances. The lintel selected for the abscissa scale because it dramatically illustrates the other limiting condition of passage, that there is a smallest opening through which one cannot pass at all. This limit is approximately equal to the sum of chest and thigh thickness, about as small as one can compress the body in a hurdle position before it is necessary to change to a crawling position.

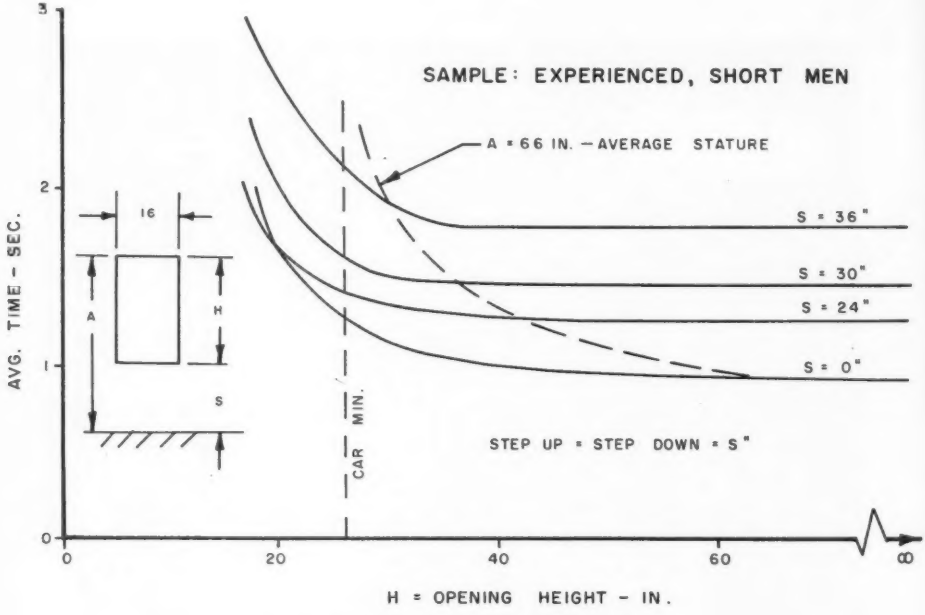


Fig. 14. The effect of opening height on exit time.
Subjects: Ten males. Age range 21–39 yr
Height range 63½–66 in.
Weight range 120–160 lb

height equal to maximum body stature is 66 in. for these subjects, and the relation of time to opening height for this fixed lintel height ($A = 66$) is indicated on the graph by the dashed line. It will be noted that the curve for 36 in. step distance does not level out at the point where $A = 66$. This is attributed to effects of crotch interference causing a change in technique.

The variable H, called height of opening, was

The effects of varying opening height cannot be separated from those of sill height except as a convenience for discussion, depending on the fixed dimensions in the design problem at hand. Thus, if the fixed dimension is lintel height and H is varied, then curves such as shown in Fig. 15 are obtained from the same data as Fig. 14. The effects of fixing H and varying step distance will be discussed under the topic Step Distance.

Width of Opening

The effect of opening width is not a major problem in present aircraft design as shown in another series of tests with a variety of subjects of varying sizes. The 19 or 20 in. required to eliminate most of the restrictive effects of width is readily achieved between conventional frame spacing (Fig. 16).

up to sill equals step down to wing, one may plot the same data of Figs. 14 and 15 in terms of step distance (S) for several fixed opening heights (H) with the results shown in Fig. 17. It is seen that time varies little as step distance increases up to approximately 25 in., but it rises in an accelerated manner thereafter.

It is not possible to distinguish accurately

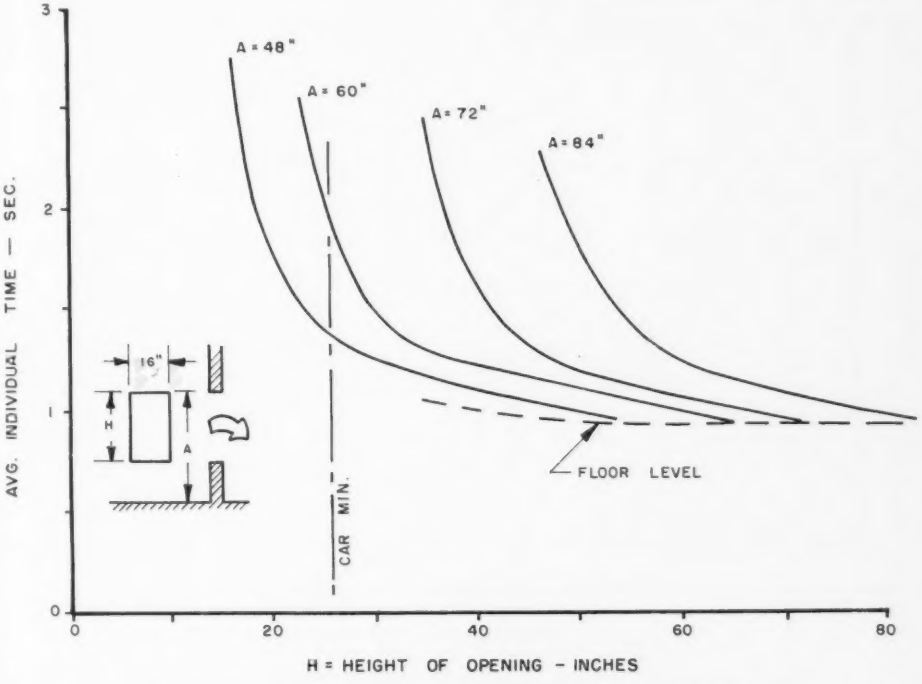


Fig. 15. The effect of opening height on exit time when lintel height is fixed.
Subjects: Ten males. Age range 21–39 yr
Height range 63½–66 in.
Weight range 120–160 lb

Step Distance

Various adaptations are possible to reduce the effects of large step distances such as sitting on the sill, stepping up on the sill, vaulting etc. However, as shown previously, the step distance conformation of the exit can have a pronounced effect on exit time.

Considering first the condition where step

between the effects of step up and step down, but various combinations may be tested to determine the effects of changing one while holding the other constant. Fig. 18 is one example of a rather detailed investigation of many combinations of step-up and step-down conditions using a fixed opening 20 in. wide by 24 in. high. A different group of subjects

was used in this series. A three-dimensional graph is used to overcome the problems of presentation of two independent variables with overlapping lines. This graph shows a broad area of nearly optimum conditions in the region between 12 in. and 30 in. step up and between 10 in. and 25 in. step down.

Step-up and step-down effects are generally less important on larger openings. At very low step distances stooping and crawling techniques are not required if the lintel height is not too low, and at high step distances one can step on the sill, then jump down to the lower level, if not restricted by a small opening.

In general, the maximum limits on step distance now used in the Civil Air Regulation[1] (29 in. step up and 36 in. step down for a type IV exit) seem to be reasonable limiting conditions for most exits.

Auxiliary Step Platforms

The possibility of reducing step distance with an auxiliary platform outside the exit was also explored. Two sizes of platform were studied. The smaller extended 6 in. out from the edge of the exit and was 12 in. wide. Although an important aid to short persons in a high step-down test, it proved difficult to find the first time through, and was of no aid at all to tall men. The larger size platform was selected from observations of subjects foot placement on regular tests, and from simple checks of maximum foot placement envelopes with large and small subjects. It was also 12 in. wide, but extended 15 in. out from the exit wall. The results of tests with this platform in a horizontal position at various distances from the horizon-

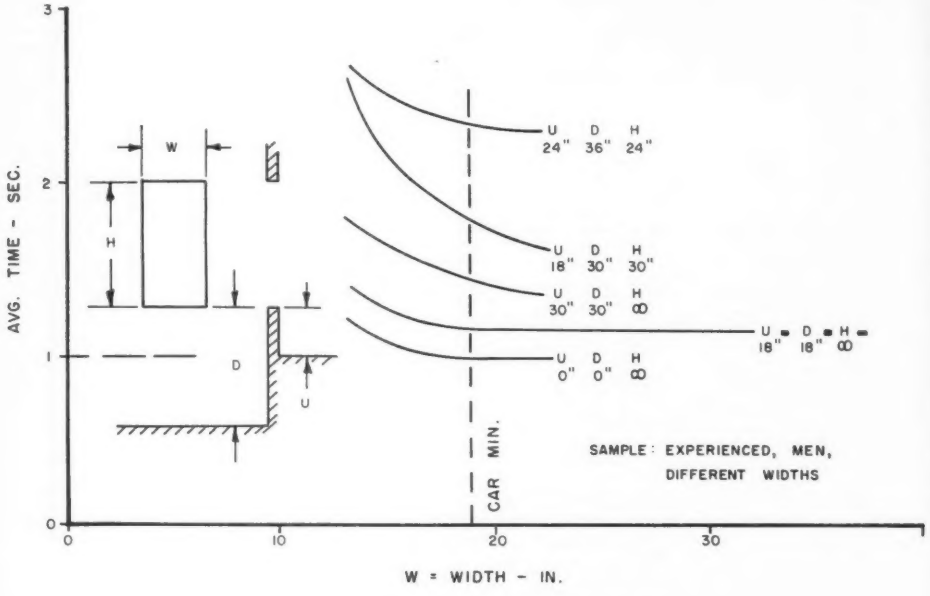


Fig. 16. The effect of opening width on exit time.
Subjects: Six males. Age range 23–50 yr
Height range 68–70½ in.
Weight range 145–225 lb

[1] Civil Air Regulation is hereafter referred to as CAR.

tal surface representing an airplane wing are depicted in Fig. 19 for two conditions of passenger seat placement. Slanted configurations with the outboard edge lower than the inboard edge were also tested (Fig. 20). The effect of slant was to give extra impetus to the subject, but was only effective on the locations test with a larger opening (H = 38 in.) and smaller step-down condition (32 in.) showed that a step 12 in. above the wing was a deterrent to escape (Fig. 21) rather than an aid.

On the basis of these limited data it appears that an auxiliary step is beneficial if the sill to wing distance is extremely high (over 36 in.)

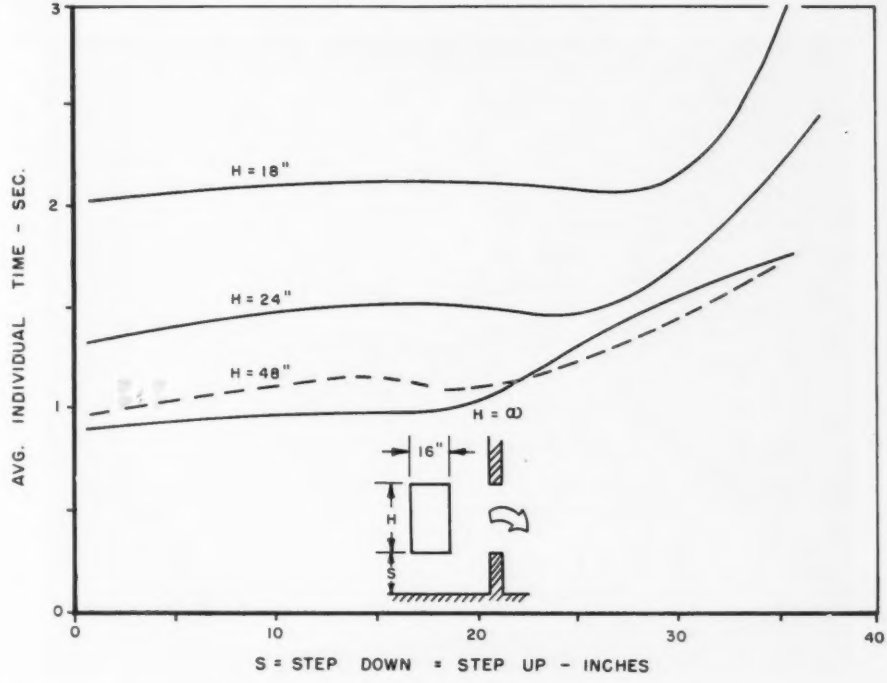


Fig. 17. The effect of step distance on exit time.
Subjects: Ten males. Age range 21–39 yr
Height range 63½–66 in.
Weight range 120–160 lb

lower than the optimum height for a horizontal step.

Further analysis of the data showed that the auxiliary step produced significantly longer exit time than the same height of complete wing surface. Therefore, it must be used with caution. It appears that the step, under the conditions of Fig. 19, must be at least 6 in. higher than the wing level to begin to be effective. A but must be carefully checked for real benefit for a sill to wing distance less than 36 in.

Seat Interferences

Analysis of the data involving seats near exits indicated that the presence of a seat below the exit may be an interference for low step distances, but an aid to high step distances, both inside and outside the aircraft (Fig. 22).

Each combination of step distances must be evaluated to determine if large effects will result. Studies of several longitudinal seat locations indicate that the escape time is essentially that for "seat clear" conditions until the seat cushion extends across about half of the width of the exit. There is essentially no change in exit time from three-quarters almost completely filled the corners. But Figs. 23 and 24 indicate that large openings can have up to 10 in. corner radii without noticeable effect. Radii of 8 in. or less produce no increase in time on the CAR Type IV exit. The actually decreasing time as radius increased for the 28 in. and the 26 in. high openings is attributable to learning. From

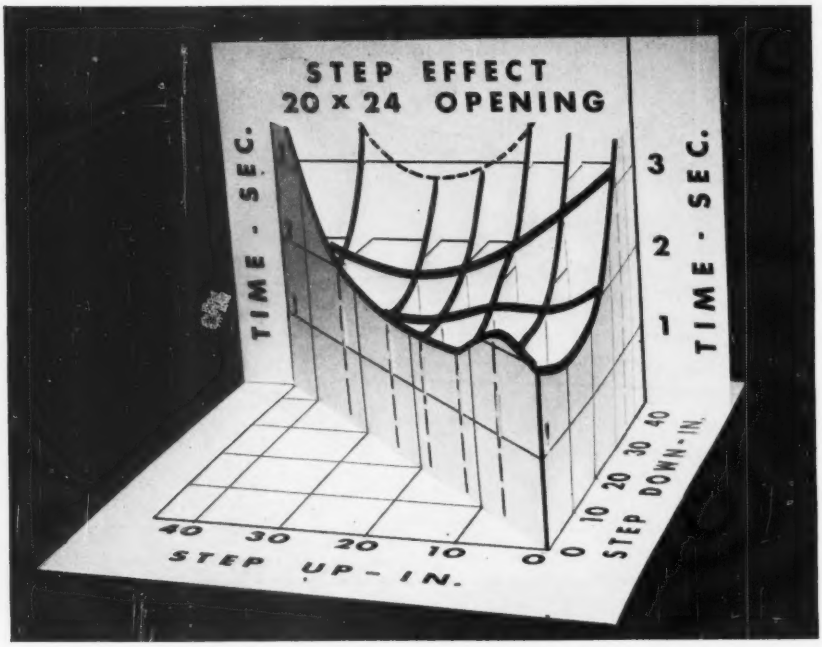


Fig. 18. Summary of the effect of varying step-up, step-down distances on exit time through a fixed opening.
Subjects: Seven males. Age range 27–37 yr
Height range 67–68¾ in.
Weight range 130–180 lb

coverage to complete coverage of the floor space below the exit.

Corner Radii

The pressure safety of the aircraft is best achieved with large corner radii, but it would appear that for small openings, the exit safety requires the opposite. On very small experimental rectangular exits some subjects indeed these data it appears that radius limits are necessary only on small exits.

Life Vests

The possible detrimental effects of wearing inflated life jackets were also investigated in conjunction with the corner radii experiments (Fig. 23). The differences in escape time due to wearing the type of inflated life jackets were

Fig. 19. The effect of auxiliary step location on exit time.
Subjects: Six males. Age range 24–33 yr
Height range 64–76 in.
Weight range 140–210 lb

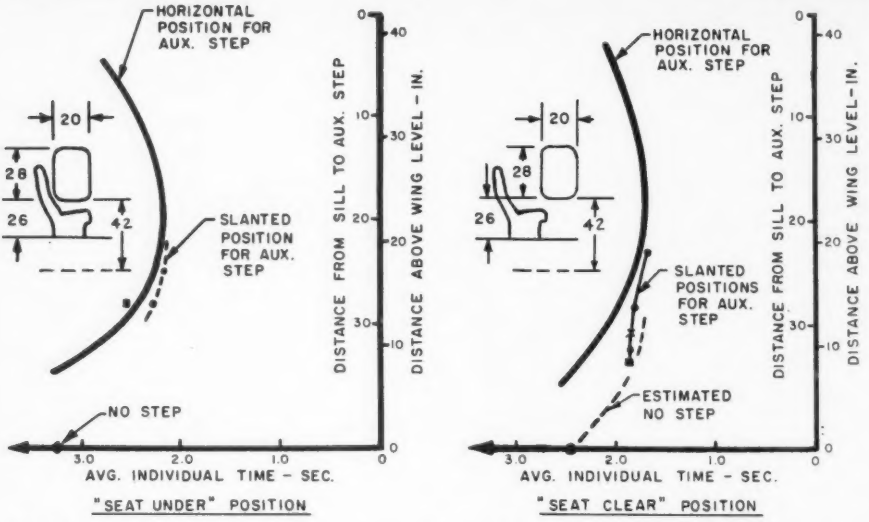


Fig. 20. The effect of a slanted auxiliary step on exit time when the outboard step is greater than the inboard step.
Subjects: Six males. Age range 24–33 yr
Height range 64–76 in. Weight range 140–210 lb

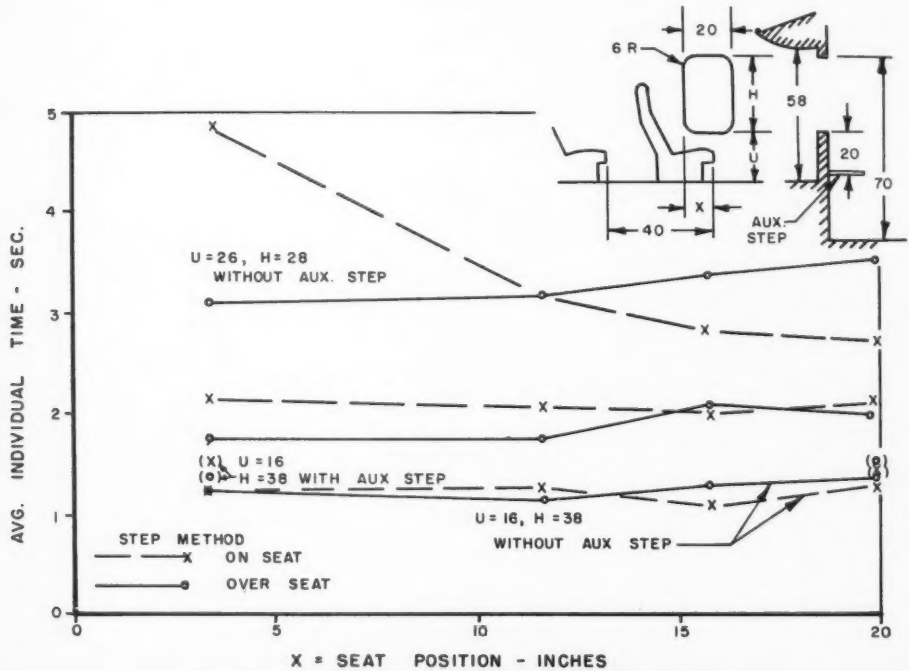


Fig. 21. The effect of seat location and auxiliary step on exit time.
Subjects: Seven males. Age range 24–33 yr
Height range 63½–76 in. Weight range 155–225 lb

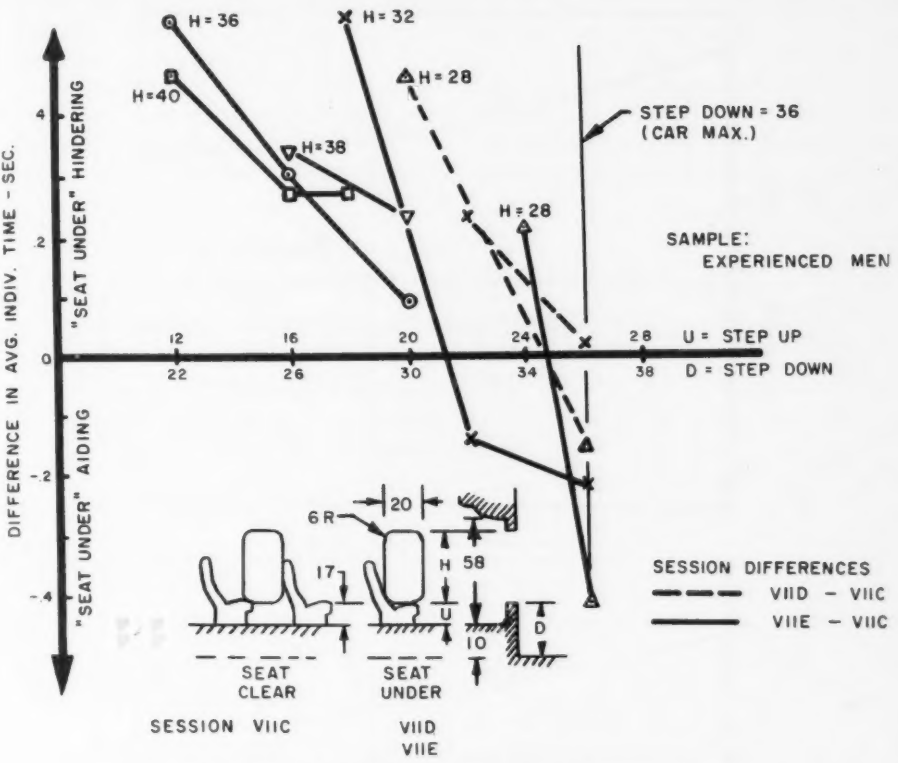


Fig. 22. The effect of seat position on exit time at different step distances.
Subjects: Five males. Age range 26–38 yr
Height range 64½–77½ in.
Weight range 125–204 lb

less than 4 per cent and were statistically insignificant at the 5 per cent level of risk for the DC–8 and CAR Type IV exits tested. While there may be larger differences between tests of inexperienced subjects than those found for the experienced subjects tested, the effects would appear to be small for this type of jacket.

Clothing

Effects of differing clothing were not studied in detail, but in several tests it was noticed that tight skirts were a real hinderance to effective egress. The problems of modesty also confound investigations of female attire, and the final test of such effects must depend on the state of the emergency, the social mores of the time and culture of the individual. In general, women were slower than men, even though in some tests they were wearing full skirts and low-heeled shoes. In the filmed tests with inexperienced subjects, the ratio of escape time for women as compared to men was 1.2 to 1.

Berth Interferences

In order to examine the possible effects of berth location interferences in a preliminary manner, several opening sizes and distance conditions were tested with combinations of

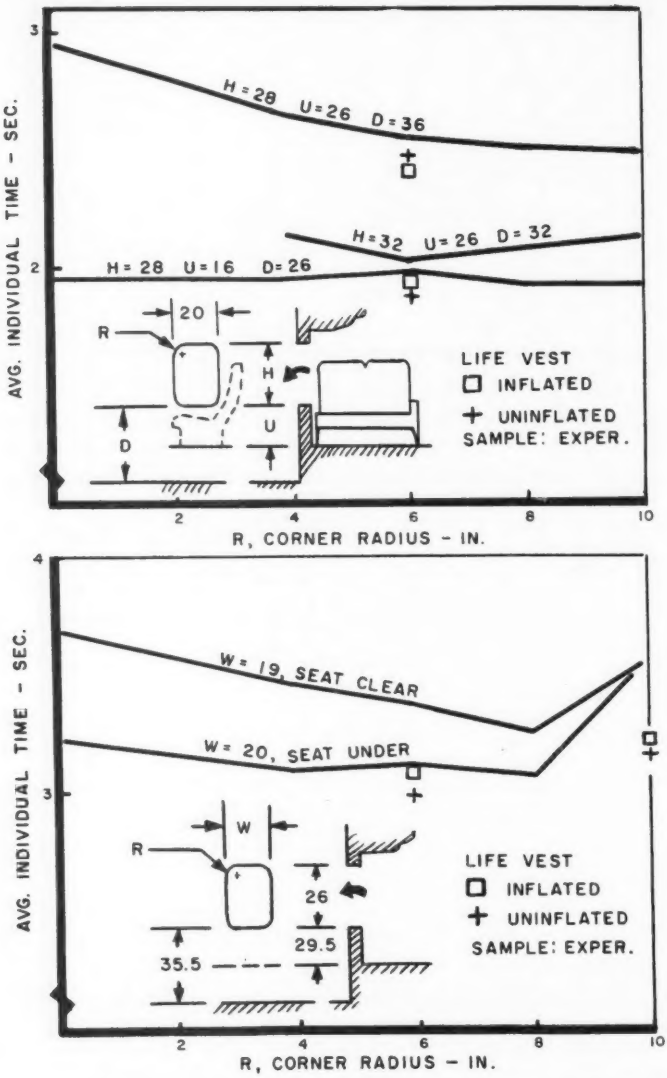


Fig. 23. The effect of corner radii, seat position and life vest on exit time.

Subjects are described as follows:

Two females. Age 23–25 yr
Height 65, 68¾ in.
Weight 120–140 lb

Three males. Age 33, 30, 27 yr
Height 76, 70½, 65 in.
Weight 200, 225, 145 lb

upper and lower berth interferences simulated. The results are presented in Fig. 24.

It appears from these data that there is only slight interference effect due to the berths. However, a very marked difficulty was experienced by the subjects as they went through

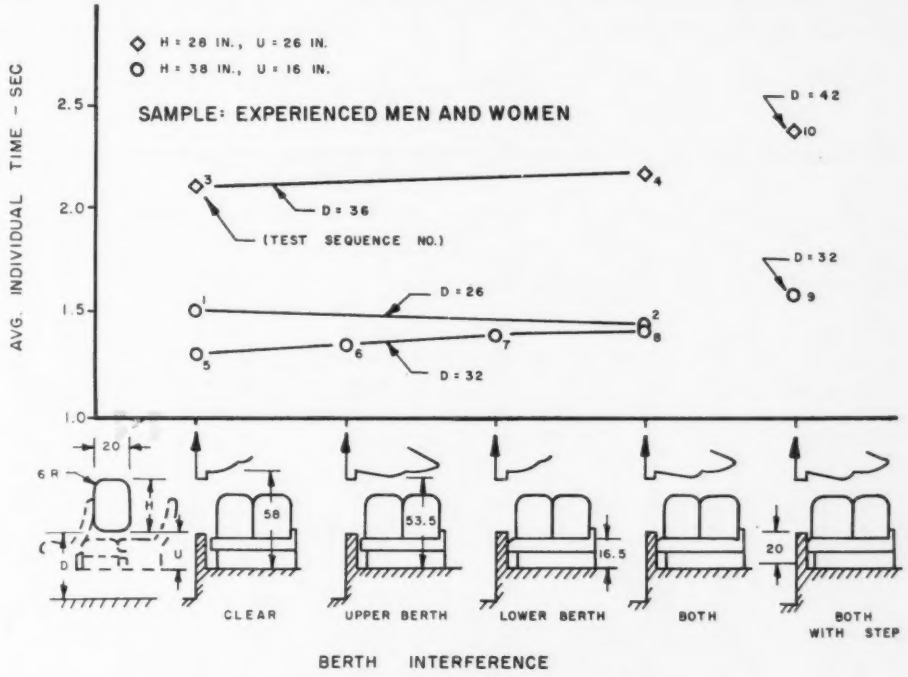


Fig. 24. The effect of berth interference on exit time.

Subjects are described as follows:

Three females. Age 29, 24, 43 yr
Height 66¼, 65¾, 64 in.
Weight 137, 126, 120 lb

Nine males. Age range 25–44 yr
Height range 67–74 in.
Weight range 145–193 lb

the small exit with the combination of effects of both berths and the auxiliary step. It is definitely an awkward configuration.

Body Dimensions

Several correlations of exit time with standard body dimensions have already been mentioned. In addition to these rather gross studies, there was initiated a study of individual differences in agility, as predicted by static measurements of limits of body movement and by age. The preliminary results indicated that height and age were somewhat predictive with some exits, but other factors clouded the issue. The combination of leg lift and body bend dimensions showed some correlations with simple walk-through type exits, so there is hope that further study will bring forth useful results.

EVALUATION OF DC-8 OVERWING EMERGENCY EXIT DESIGN PROPOSALS

Space does not allow a detailed description and discussion of the effects of changes in the several design variables, but a short summary of the most important tests will be given. Readers who have a deeper interest in the subject are referred to the basic report.[23]

A series of tests was performed using approximately 10 naïve subjects per test to compare proposed DC-8 exits with CAR Type III and IV exits. Composition of the sample is compared to that of the estimated airline population in Table VIII.

The dimensions of the exits are shown in Table IX.

The results are shown in Tables IX and X

TABLE VIII (A) and (B)

(A) Comparison of Age and Sex Distribution of Test Subjects to (B) Estimated Airline Passenger Population (First Movie Runs—Session M-1)

(A) TEST SUBJECTS

Group	Age group	Male No.	Male %*	Female No.	Female %*	Total No.	Total %*
I	17–24			1	10	1	10
	25–44	6	60	1	10	7	70
	45–65	1	10	1	10	2	20
	Over 65						
	Total	7	70	3	30	10	100
II	17–24			1	9.1	1	9.1
	25–44	7	63.6	2	18.2	9	81.8
	45–65	1	9.1			1	9.1
	Over 65						
	Total	8	72.7	3	27.3	11	100
III	17–24	2	18.2	1	9.1	3	27.3
	25–44	4	36.3	2	18.2	6	54.5
	45–65	2	18.2			2	18.2
	Over 65						
	Total	8	72.7	3	27.3	11	100
IV	17–24			1	11.1	1	11.1
	25–44	5	55.6	2	22.2	7	77.8
	45–65	1	11.1			1	11.1
	Over 65						
	Total	6	66.7	3	33.3	9	100
V	17–24	1	11.1			1	11.1
	25–44	4	44.5	1	11.1	5	55.6
	45–65	1	11.1	2	22.2	3	33.3
	Over 65						
	Total	6	66.7	3	33.3	9	100
VI	17–24	1	16.7	2	33.3	3	50
	25–44	2	33.3			2	33.3
	45–65						
	Over 65	1	16.7			1	16.7
	Total	4	66.7	2	33.3	6	100
VII	17–24			1	10	1	10
	25–44	5	50	2	20	7	70
	45–65	2	20			2	20
	Over 65						
	Total	7	70	3	30	10	100

* Per cent of the total test subjects.

(B) ESTIMATED DISTRIBUTION AIRLINE PASSENGERS[8, 11]

Age Group	Male %	Female %	Total %
17–24	4	3	7
25–44	39	15	54
45–65	25	11	36
Over 65	2	1	3
Total	70	30	100

TABLE IX

Results of First Movie Runs—Session M-1

Exit type	*Opening size (in.)*	*Step up (in.)*	*Step down (in.)*	*Average time/person (sec)*	*No. of persons evacuated in 81 sec**	*Number in sample*		
						male	*female*	*total*
CAR III	20 × 36	20.5	26.5	2.0	40.5	7	3	10
CAR IV	26 × 26	29.5	35.5	3.44†	23.5	8	3	11
				3.68‡	22.0	14	4	18
				5.86§	14.9	14	5	19
DC-8 Fwd. Wing	20 × 38	16	26	1.99	40.7	8	3	11
DC-8 Fwd. Wing	20 × 28	26	36	2.77	29.2	14	6	20
DC-8 Aft Wing	20 × 38	16	32	1.90	42.6	6	3	9
DC-8 Aft Wing with Step	20 × 28	26	20 in. to step	2.77	29.2	10	5	15
DC-8 Aft Wing	20 × 28	26	42	4.15	19.5	7	3	10
						66	27	93

* 81 sec + (9 sec preparation time) = 90 sec fire danger limit.
† Inexperienced Group II (see Table VIII).
‡ Groups I and II combined, excluding Subject No. 18 (Session M-1).
§ Groups I and II combined, including Subject No. 18.

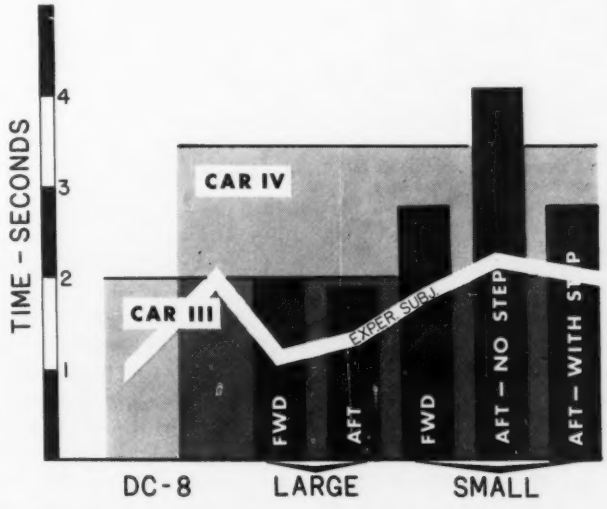


Fig. 25. Average times for egress through overwing exits for experienced subjects. The naive subject data are those reported in Table IX. Subjects are described in Table VIII. The experience subjects were 10 malesas follows:

Age range 23–41 yr.
Height range 64½–72⅓ in.
Weight range 140–190 lb

TABLE X

Comparison of CAR and DC–8 Exits (First Movie Runs—Session M–1)

Test No.	Exit type	Average grouped time (sec)	Average time second light (sec)	Standard deviation (sec)	Standard error (sec)	Significance at 5% level: 1–C CAR III	5A CAR IV	5 & 5A CAR IV*	5A CAR IV†	5 & 5A CAR IV†	7 DC–8 Fwd. (38″)	8 DC–8 Fwd. (28″)	8A DC–8 Fwd. (28″)	8 & 8A DC–8 Fwd. (28″)	9 DC–8 Aft (38″)	10 DC–8 Aft (28″) (with step)	12 DC–8 Aft (28″) (no step)
I–C	CAR III	2.00	1.97	0.87	0.29		S	S	S		I	I	S	S	I	S	S
5	CAR IV	3.68	3.68	2.17	0.687			I	I		S	I	I	I	S	I	I
5A	CAR IV*	3.03	2.715	0.703	0.385				I		I	I	I	I	I	I	I
5 & 5A	CAR IV*	3.44	3.32	1.745	0.463						S	I	I	I	S	I	I
5A	CAR IV†	7.46	8.037	14.1	5.33												
5 & 5A	CAR IV†	5.38	5.47	9.06	2.19												
7	DC–8 Fwd. (38″)	1.99	1.99	0.782	0.248							I	S	S	I	S	S
8	DC–8 Fwd. (28″)	2.58	2.62	0.953	0.337								I	I	I	I	I
8A	DC–8 Fwd. (28″)	2.92	2.91	0.880	0.278									I	S	I	S
8 & 8A	DC–8 Fwd. (28″)	2.77	2.78	0.890	0.210										S	I	S
9	DC–8 Aft (38″)	1.90	1.88	0.710	0.252											S	S
10	DC–8 Aft (28″) (with step)	2.77	2.78	0.905	0.242												I
12	DC–8 Aft (28″) (no step)	4.15	4.32	2.39	0.795												

* Not including Subject No. 18.
† Normal statistical tests are misleading here due to one exceedingly high value of Subject No. 18.
I = Insignificant difference between means.
S = Significant difference between means.

and graphically compared to results from tests with a group of experienced male subjects in Fig. 25. These results indicate that the proposed small forward DC–8 exit was considerably better than the CAR Type IV. Fig. 25 shows that the auxiliary step installed under the proposed aft small overwing exit brings the aft exit time down to that of the forward small exit.

The CAR III and DC–8 large forward and aft overwing exits are essentially equal, even though the aft exit has a longer step down (32 vs. 26 in.). The equivalence between the latter two exits was further investigated using a larger inexperienced sample (25 persons). The DC–8 forward and aft exits, with "seats clear" and "seats under" the exit, were tested. Also a test of the CAR IV exit with the seat clear was performed for further statistical reliability of this important reference standard.

The subjects for these tests were run once as completely inexperienced samples and once again in the same exit but with a different seat location. Their age and sex distribution were

TABLE XI (A) and (B)

(A) Comparison of Age and Sex Distribution of Test Subjects to (B) Estimated Airline Passenger Population (Second Movie Runs—Session IX)

(A) TEST SUBJECTS

Group	Age group	Male No.	Male %	Female No.	Female %	Total No.	Total %
A	Under 20			1	4	1	4
	20–29	3	12	1	4	4	16
	30–39	6	24	2	8	8	32
	40–49	5	20	2	8	7	28
	50–60	3	12	2	8	5	20
	Over 60						
	Total	17	68	8	32	25	100
B	Under 20			1	4	1	4
	20–29	3	12	1	4	4	16
	30–39	6	24	1	4	7	28
	40–49	3	12	3	12	6	24
	50–60	2	8	3	12	5	20
	Over 60	1	4	1	4	2	8
	Total	15	60	10	40	25	100
C	Under 20			1	3.8	1	3.8
	20–29	2	7.7	2	7.7	4	15.4
	30–39	5	19.3	1	3.8	6	23.1
	40–49	8	30.9	2	7.7	10	31.5
	50–60			3	11.5	3	11.5
	Over 60	1	3.8	1	3.8	2	7.7
	Total	16	61.7	10	38.3	26	100
D	Under 20			1	3.7	1	3.7
	20–29	3	11.1	1	3.7	4	14.8
	30–39	6	22.2	2	7.4	8	29.6
	40–49	7	25.9	2	7.4	9	32.3
	50–60	2	7.4	2	7.4	4	14.8
	Over 60	1	3.7			1	3.7
	Total	19	70.3	8	29.6	27	100

(B) ESTIMATED DISTRIBUTION AIRLINE PASSENGERS[8, 11]

Age group	Male %	Female %	Total %
Under 20	1	1	2
20–29	10	7	17
30–39	21	7	28
40–49	21	6	27
50–60	12	6	18
Over 60	5	3	8
Total	70	30	100

proportioned to match the available data on airline populations and the test groups were matched with each other, as shown in Table XI. The results of these studies are given in Tables XII and XIII. These data indicate that the exit time from the aft exit is a little slower than that through the forward exit. The difference between the two is not significant at the 10 per cent level either with or without seats under the exit. Graphs of individual exit time versus age for both exits are shown in Figs. 26 and 27. Comparison of the two shows that the effect of age is much greater in egress through the aft exit, but that the average time for the younger groups is actually lower through the aft exit than through the forward exit.

This result is in agreement with the data of the first filmed tests, where a somewhat younger group of subjects were tested. It appeared that the escape time through the aft is more sensitive to subject selection than that through the forward exit but is essentially equivalent in escape time for subjects closely matched to the estimated airline population.

Though the above study showed that there was negligible difference between the exits, it was felt that the effect of an auxiliary step

should be studied. A test using experienced subjects was performed with the aft large exit configuration, using an auxiliary step 20 in. below the sill, and two different seat conditions. The auxiliary step height was near the expected location required by structural design factors, and well within the step-down legal limits. The test results are those shown in Fig. 21.

variability of the small, difficult exits of which the Type IV is typical is the cause of the wide range of values. A suggested rule of thumb stating that one CAR III equals two CAR IV is within the experimental error.

The results of this study led to a final decision, based on the proposed passenger capacity of the aircraft, to use four large

TABLE XII

Results of Second Movie Runs—Session IX

Exit type	*Opening size (in.)*	*Step up (in.)*	*Step down (in.)*	*Subject group*	*Run no.*	*Average time/person (sec)*	*Number in Sample*		
							male	*female*	*total*
DC-8 Fwd. Wing Seat Under	20 × 38	16	26	C	1	1.827	16	10	26
DC-8 Fwd. Wing Seat Clear	20 × 38	16	26	C	2	1.604	16	10	26
DC-8 Aft Wing Seat Under	20 × 38	16	32	A	2	2.137	17	8	25
				B	1	2.143	15	10	25
DC-8 Aft Wing Seat Clear	20 × 38	16	32	A	1	2.141	17	8	25
				B	2	1.726	15	10	25
CAR IV Seat Under	19 × 26	29.5	35.5	D	2	3.699	19	8	27
CAR IV Seat Clear	19 × 26	29.5	35.5	D	1	3.587	19	8	27

$$\frac{\text{Rate DC-8 Fwd. (U)}}{\text{Rate CAR IV (U)}} = \frac{1/1.82}{1/3.699} = 2.03 \qquad \frac{\text{DC-8 Fwd. (C)}}{\text{CAR IV (C)}} = \frac{1/1.604}{1/3.587} = 2.23$$

U = Seat Under. C = Seat Clear.

Also shown in Fig. 21 are the results of some other tests with the small exits and differing seat locations. It is seen that the auxiliary platform has a very small effect on performance under the conditions of this experiment. It was concluded that the auxiliary step would be a needless complication.

Results of the CAR Type III and Type IV tests showed that the Type III exit may be from 1.7 to 3 times as fast as the Type IV, depending on the subjects studied. The high

(20 in. × 38 in.) overwing exits in addition to the four full-sized passenger and service doors of the aircraft.

Regulations

In the final analysis, the designer must abide by the regulations concerning the design of exits which are set by the regulating body which governs his industry. These may be adequate or they may be outmoded, and his particular design limitations may cause him to

TABLE XIII

Comparison of CAR and DC–8 Exits (Session IX)

Test no.	Exit type	Average group time (sec)	Average time second light (sec)	Standard deviation (sec)	Standard error (sec)	DC–8 Aft—38″ Seat Clear 13	DC–8 Aft—38″ Seat Under 14	DC–8 Aft—38″ Seat Under 15	DC–8 Aft—38″ Seat Clear 16	DC–8 Fwd.—38″ Seat Under 17	DC–8 Fwd.—38″ Seat Clear 18	CAR IV Seat Clear 19	CAR IV Seat Under 20
13	DC–8 Aft—38″ Seat Clear	2.141	2.135	1.10	0.2200		I	I	I	I	S	S	S
14	DC–8 Aft—38″ Seat Under	2.137	2.147	0.954	0.1908			I	I	I	S	S	S
15	DC–8 Aft—38″ Seat Under	2.143	2.157	1.187	0.2422				I	I	S	S	S
16	DC–8 Aft—38″ Seat Clear	1.726	1.733	0.754	0.1539					I	I	S	S
17	DC–8 Fwd.—38″ Seat Under	1.827	1.789	0.574	0.1111						I	S	S
18	DC–8 Fwd.—38″ Seat Clear	1.604	1.593	0.425	0.0867							S	S
19	CAR IV Seat Clear	3.587	3.626	2.09	0.4098								I
20	CAR IV Seat Under	3.699	3.743	2.002	0.3925								

I = Insignificant difference between means.
S = Significant difference between means.

request deviations from the existing statutes. To expect approval of such deviations he needs extensive, accurate data to show an equivalent safety provision can be installed by use of different shape or size of exit, or a different escape device.

The regulations concerning emergency exits have been modified over the years as public disasters have brought out the need for legislation and as new data for design are made available. However, the nature of regulations is to be specific and conservative. As a result they are often inflexible. In aircraft design the weight and space requirements are so important that it is worth considerable effort to obtain the optimum solution that will fulfill the need and still meet the true safety requirements.

DEVELOPMENT OF DESIGN DATA GRAPHS

With the foregoing data on experimental subjects to indicate the nature of trends as exit dimensions vary, it is now possible to set up a rational framework by which to compare studies performed with naïve subjects. The important factors are step-up and step-down distances, opening height, width and seat position. The width was shown to be adequate with nearly negligible effect on escape time in

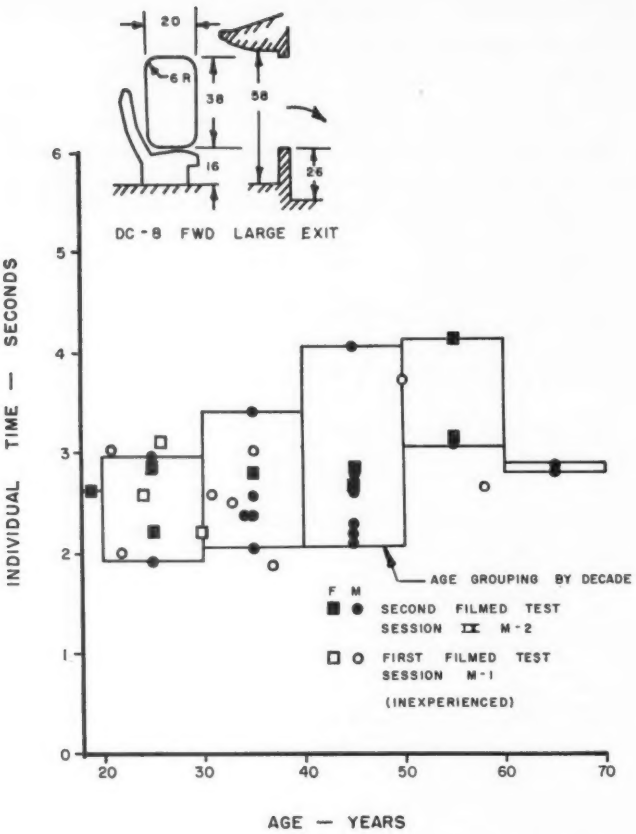


Fig. 26. The effect of age on exit time through the large forward exit of the DC-8. The subjects are those described in Tables VIII and XI.

the range 19–24 in. Since most aircraft exits can meet this criterion, we need not develop test data concerned with exits of less than this width. Seat position is perhaps the last to be decided in aircraft interior arrangements, and is variable in present-day flexible seat spacing. Therefore, seat spacing should not be included in primary design data graphs. Primary structural and aerodynamic considerations set the floor-to-wing distance. Since the step-up and step-down heights are related to this distance, a series of graphs, each based on a different value of this dimension is needed. There remain two variables, height of opening and step distance relative to one of the levels, say the floor. Selecting the height of opening as the abscissa and escape time as the ordinate, we can then plot the various step distances as a family of curves as shown in Fig. 28.

The experimental data show great variability due to uncontrolled differences in subject selection, timing methods, and other artifacts of the experiment. There is also an expected variation in the same individual. Thus parts

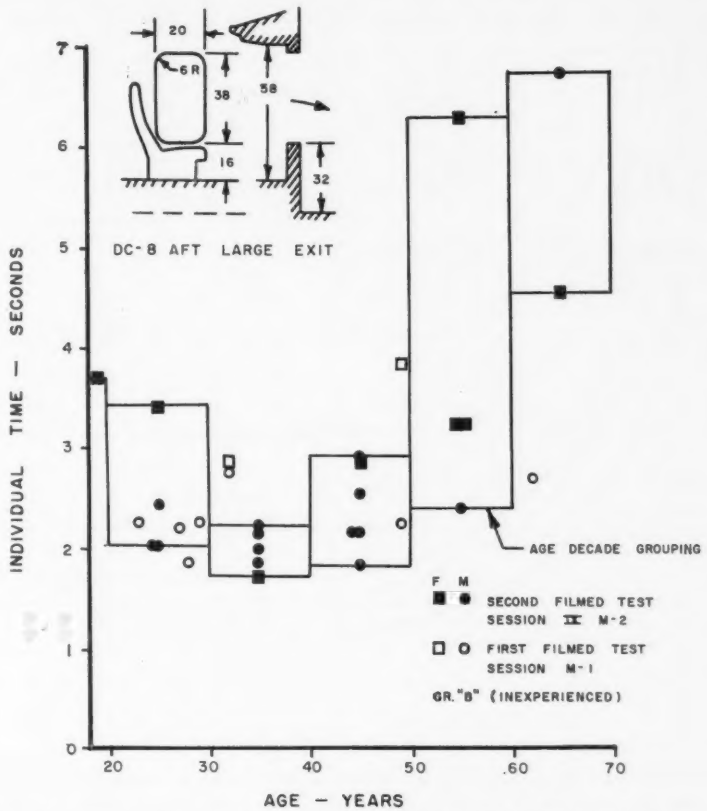


Fig. 27. The effect of age on exit time through the large aft exit of the DC-8. The subjects are those described in Tables VIII and XI.

of these curves are admittedly poor predictors of the expected escape time values. However, the direction of future study is indicated. Standardized methods of subject selection and timing are needed. Then as any future studies are performed, standard methods may be employed. One additional point per test is then available to plot on the graph and more accurate estimates than those shown may be determined. Eventually such graphs may supplant an arbitrary table of exits such as shown in Table XIV. "Equivalent safety" will then be the item to be demonstrated by the manufacturer, and it may be done by means of the graphs instead of tests.

TABLE XIV

The Relation Between Passenger Seating Capacity and the Type and Number of Exits Provided on Each Side of an Airplane (from CAR Amendment 46–5; effective April 9, 1957)

Passenger seating capacity (inclusive)	*Emergency exits required on each side of fuselage*			
	Type I	*Type II*	*Type III*	*Type IV*
1 to 19			1	
20 to 39		1		1
40 to 59	1			1
60 to 79	1		1	
80 to 109	1		1	1
110 to 139	2		1	
140 to 179	2		2	
180 to 219	2	2		

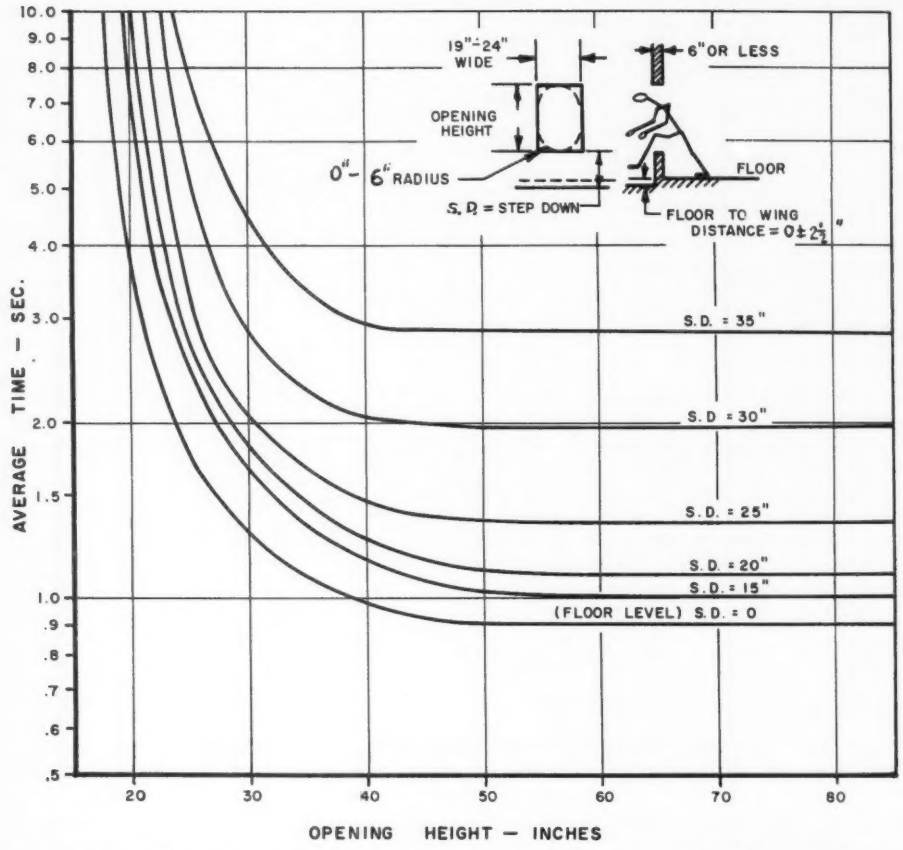


Fig. 28. Suggested form of graph for new regulation, expressing escape time in terms of exit geometry. Data for floor to wing distance of $0 \pm 2\frac{1}{2}$ in. are shown. Additional graphs would show similar curves for different ranges of floor-to-wing distances.

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CHARLES A. BAKER and WILLIAM C. STEEDMAN (*Perceived Movement in Depth As a Function of Luminance and Velocity*). See page 104, *Human Factors,* May, 1960, Vol. 2, No. 2.

JOHN A. ROEBUCK, Jr., and B. H. LEVEDAHL (*Aircraft Ground Emergency Exit Design Considerations*)

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He is a founding member of the national Human Factors Society and of the Human Factors Society, Los Angeles Chapter, in which he was program chairman for a year. He is also chairman of the Aeromedical Engineering Society. Mr. Roebuck has authored or co-authored 11 research papers and company reports.

BLAINE H. LEVEDAHL. See page 75, *Human Factors,* August, 1959, Vol. 1, No. 3.

Editorial

SIMULATORS AND TRAINING AIDS

Keeping up with developments is a hard business. The simulation of anticipated conditions is a large part of current human factors efforts, and the advanced aspects of personnel training to meet anticipated needs in new man-machine systems is still another part of human factors, at least by specification. But it may be well to look backward as well as forward. For example, an historical note relevant to the subject of simulators and training aids is quoted below.

"The Roman expedition to Sicily defeated the Carthaginians and Hiero separately, and in the year following entered into alliance with Hiero against the Carthaginians. To drive the Carthaginians from Sicily and protect their own coast the Romans required a navy. Within sixty days they built 120 ships, using a grounded Carthaginian vessel for a model, and trained crews to row on wooden stages erected on land. With this fleet they won a battle off Mylae (260 B.C.) and with another a greater battle off Ecnomus on the Sicilian coast (256 B.C.). Now the Romans could invade Carthage."[1]

Historical examples in areas of interest to human factors specialists might broaden our perspectives. Perhaps with the co-operation of our readers, we can publish selections on a number of subjects, not necessarily military applications.

Stanley Lippert

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1 HADAS, MOSES: *A History of Rome From Its Origins to 529 A.D. As Told by the Roman Historians.* Doubleday & Company, Inc.: Garden City, New York, 1956, page 29. (Quoted by permission of Doubleday & Company, Inc.)

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